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VOL. 41 NO. 377 MAY 1955

THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 26 Portland Place, London, W.1, on 12 January 1955, the Chair being taken by the President, Lt.-Col. S. J. M. Auld, O.B.E., M.C., D.Sc.

The General Secretary read the minutes of the previous meeting, which were confirmed and signed as a correct record. He also announced the names of members elected since the previous meeting, and gave notice of the date of the next meeting.

The Chairman introduced Mr A. T. Wright who then presented the following paper in summary.

INSURANCE IN THE OIL INDUSTRY

By A. T. WRIGHT * (*Associate Member*)

Although insurance is an integral part of present day commerce and industry, the question might be asked what are the objects of insurance. This is perhaps best answered by quoting from an Elizabethan Act of 1601 dealing with marine insurance in which its objects are expressed in the following words—" by means whereof it cometh to pass that upon the loss or perishing of any ship there followeth not the undoing of any man, but the loss lighteth rather easily upon many than heavy upon few, and rather upon them that adventure not than upon those who do adventure; whereby all merchants, especially those of the younger sort, are allured to venture more willingly and more freely."

INTRODUCTION

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transport, and the use of oil-driven machinery in industry and agriculture.

In the early stages of the industry's development the handling of petroleum products and their uses in various spheres introduced a variety of new hazards from the insurance point of view. It was therefore necessary to devise appropriate protective measures; and the insurance companies played an important part in this respect. On the other hand, the use of oil as a source of energy has contributed very largely to the high standard of modern fire fighting methods, not only within the industry, but also elsewhere, *e.g.* fire fighting facilities can now be brought to the scene of a fire in a fraction of the time formerly taken.

In considering the history and origin of insurance it is necessary to deal with the various branches individually, as although the basic principle of insurance is the same, the development of the various kinds of insurance spring from the changes which have occurred during the centuries in the social and economic patterns of various countries.

MARINE INSURANCE

Whilst it is known that marine insurance in various forms existed prior to authentic historical records, its introduction to England may be largely attributed to the Lombards, who, following the sacking of Rome and destruction of its commerce in the early 13th century, migrated to England for political sanctuary. Their money-lending activities subsequently brought them into disfavour, and by the 17th century they were forced to leave the country.

The credit of introducing marine insurance into England may also be shared with the Hanseatic merchants, who came from several North European towns, but by the year 1597 the Hanseatics were expelled from the country by Royal decree.

It will be seen that marine insurance, having been introduced to England by the Lombards and Hanseatics, was now denied to them as an avenue of commerce and the field left clear for Englishmen of foresight.

In 1601, in order to minimize disputes over the meaning of insurance policies, the first statute dealing with marine insurance was given legal effect. The statute sought to encourage the growth of marine insurance, laid down some of its basic principles, and provided the procedure for the settlement of disputes.

With the advent of coffee houses in the 17th century the proprietors saw the advantage of attracting clientele with common interests. Prominent amongst them was Edward Lloyd, whose premises in Tower Street, London, became well known among men of seafaring interests, and who, with a view to improving his business, ultimately moved his premises to Lombard Street, where the seeds of marine insurance had been planted by the Lombards some centuries earlier.

It was not until 1774, however, that John Julius Angerstein, who became known as the "Father of Lloyd's," obtained accommodation for the underwriters and brokers in the Royal Exchange building, and this step marked the beginning of a new era for Lloyd's.

* The British Petroleum Co. Ltd.

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INTRODUCTION

AN OUTLINE of the history and origin of insurance might be of some interest, but before touching upon this aspect consider the impact of the development of the oil industry during the 20th century upon insurance. It is to be found in almost every branch of insurance—in marine circles by virtue of the importance which tankers play in the mercantile marine of the world today and the use of oil as a means of propulsion for all types of vessel; in general insurance circles through the development of petrol- and oil-driven vehicles and aircraft as a means of transport, and the use of oil-driven machinery in industry and agriculture.

In the early stages of the industry's development the handling of petroleum products and their uses in various spheres introduced a variety of new hazards from the insurance point of view. It was therefore necessary to devise appropriate protective measures; and the insurance companies played an important part in this respect. On the other hand, the use of oil as a source of energy has contributed very largely to the high standard of modern fire fighting methods, not only within the industry, but also elsewhere, *e.g.* fire fighting facilities can now be brought to the scene of a fire in a fraction of the time formerly taken.

In considering the history and origin of insurance it is necessary to deal with the various branches individually, as although the basic principle of insurance is the same, the development of the various kinds of insurance spring from the changes which have occurred during the centuries in the social and economic patterns of various countries.

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Having touched upon the early growth of Lloyd's, who may be regarded as having epitomized the private underwriting fraternity, the activities of the marine insurance companies come into focus. In the year 1720 two joint-stock corporations were granted Royal Charters giving them a monopoly of marine insurance so far as companies were concerned. Eventually this monopoly was removed, whereafter companies were founded in quick succession, which, together with the resources of Lloyd's underwriters, enabled London to become the centre of the world's marine insurance market.

About the middle of the 19th century, coincident with the increase in size and value of vessels and their cargoes and the resultant increase in liability arising from collision, it became the practice of shipowners to carry part of this liability under a system of mutual insurance. This marked the beginning of mutual protecting and indemnity associations, whose functions are to provide protection to shipowners in respect of the various liabilities to which they are exposed and which are not covered by the normal marine insurance policy.

FIRE INSURANCE

Another branch of insurance having ancient origins is fire insurance. It is thought that its earliest application was connected with the communes of towns and districts. The communes flourished in Assyria and other parts of the East more than 2500 years ago. The judges, priests, and magistrates were appointed for each town and district with authorized power to levy contributions from each member of the commune to provide a fund against sudden calamities such as drought and fire. If the fire was, in the judges' view, accidental, they empowered the magistrates to assess the members of the commune, either in kind or in money, and if, as was often the case, any member was unable through poor circumstances (financial) to meet his share of the contribution, the deficiency was made up from the common fund.

In Greek and Roman times guilds were formed for protection. The members of these guilds made payments towards a common fund to secure themselves against calamity, thus bringing out the fact that the only means of protection available was through mutual association.

The first indication of fire insurance in England was similarly on a mutual basis. The Anglo-Saxon guilds of the 11th century made fixed periodical payments into a common fund against loss by "fire, water, robbery, or other calamity."

In the early 17th century the Lord Chancellor issued Church Briefs or King's Letters. These briefs or letters were in fact licences entitling the sufferer of loss from fire damage to ask for funds to recoup himself for such loss or damage, and their issue continued for a long period, although the practice was open to, and in fact led to, abuse.

It was not until the year after the Great Fire of London, *i.e.* 1667, that the practice of fire insurance emerged from the purely mutual system, and commenced to develop on the lines of the present business organization. The first joint-stock, or proprietary, company was founded in 1681, and from that date other companies were founded in quick succession. It is worth noting as a matter of interest that a few of those original companies still exist.

Thus the theory of fire insurance emerged. Fire insurance is the means by which any fire loss or damage is transferred from an individual to a community, every member of which has contributed to a common fund, out of which individual losses are made good. Its aims are to accomplish that losses, possibly overwhelming, shall not fall exclusively on the owner of property destroyed, and that the loss shall be distributed over a community of persons (all exposed to the risk of a similar catastrophe). It does not directly aim at the prevention or the minimizing of a loss, but the development of fire fighting appliances and facilities, coupled with the imposition of high rates for adverse features and allowances for good features, tend to act as minimizing and preventive agents.

ACCIDENT INSURANCE

The accident branch is by far the youngest entrant into the insurance field, and it is in fact only at the middle of the 19th century that we find its first appearance (by coincidence much the same time as the first oil wells were being drilled in the U.S.A.).

As a result of the Industrial Revolution in the U.K. and in particular the development of the railway as a means of transport there arose a demand for personal accident insurance protection, and it is to this that accident insurance proper owes its beginning, although certain fidelity guarantee risks had been transacted a few years previously.

The passing of the Fatal Accident Act of 1846 focused attention upon the possibilities of providing protection against risks of accident by means of insurance. With the development of industry, and the resultant increase in the number of accidents to work-people, the next stage in accident legislation was reached with the Employers Liability Act 1880, followed by the Workmen's Compensation Act 1897. Succeeding acts increased both the scope and magnitude of benefits, insurance in certain instances being compulsory by law, until, in 1948, industrial injury compensation became a part of the State social insurance scheme. Nevertheless, employers were still left with common law liabilities to employees, this demanding in turn insurance protection, and one has only to glance through the many claims made in this direction to realize the potential liabilities still falling upon an employer. Overseas workmen's compensation legislation is still found in one way or another parallel to that which existed in the U.K. before the State took over responsibility for industrial injury compensation.

Motor vehicle insurance forms another major section of the accident branch, appearing first at the turn of the century, and now influenced largely by the Road Traffic Acts 1930–34, which made third party motor insurance compulsory in the U.K. In the earliest days the cost of a third party car insurance with a "most modest" protection of up to £100 only was £10. Fire risk could be added at £2 2*s*. per cent, but cover against accidental damage was not apparently considered an insurable risk.

Public liability insurance started also during the early 20th century, workmen's compensation legislation having emphasized the importance of legal liabilities of all kinds, and daily reports of legal proceedings now serve to reflect how vulnerable a large industrial undertaking is to claims made against them in one form or another for damages due to so-termed "negligence." Law Reform Acts of recent years have generally tended to increase rather than to decrease the liabilities of this nature attaching to industrial undertakings.

In more recent years the development of aircraft as a means of transport, has created an additional demand for a specialized type of insurance protection suitably met by those concerned in the business of insurance.

LIFE ASSURANCE

This branch of insurance first appeared towards the end of the 16th century, when a limited number of small organizations were offering to selected persons in business or the professions widow's pensions in consideration of annual payments during the life of the individual. In 1706 the first amicable societies to provide death benefits were formed, and by 1720 a number of insurance companies had commenced life assurance as it is practised today.

Industry is not so directly concerned with this branch of insurance as it is with the three main branches already referred to, namely marine, fire, and accident, but it is well known that, during recent years, insurance companies, through the life branch, have been of great assistance to industry in the establishment of group life assurance and pension schemes for employees.

From these introductory remarks on the origins and development of insurance it is seen that the system of insurance has assisted to a large degree in the development and operation of modern industry.

In oil more than in any other sphere of modern industry large capital investment is the key to growth and development, and without insurance and the security it provides private capital would not be risked to the extent that it is today.

Generally speaking, it is possible to obtain insurance protection against any fortuitous loss, for it is the business of insurance institutions at home and overseas to accept the risks of accidental loss or damage to which physical assets and the like are exposed and to provide protection in respect of the liabilities arising out of the operation of those physical assets, leaving the industry itself, associated with banking and similar institutions, to carry only the financial risks which arise from the venture of its capital in the competitive world of today.

The needs of the oil industry so far as insurance is concerned do not differ unduly from the needs of any other major industry, apart from the immensity of the capital investment involved, and the approach to the problem depends to a large extent upon the financial resources of the company and the particular risks attendant upon its operations. A newly developed concern, as also the small company, cannot be so selective as well-established major groups in the risks to be insured and those which can be borne within the company. On the other hand, if every possible hazard that exists in relation to the assets and operations of a company were insured the premium cost would constitute a heavy first charge on the company's revenue. Thus in any event there must be a certain amount of selectivity of insurance coverage by each company management.

The basic insurance needs may be classified under the following main headings:

(1) Fire and explosion insurance on shore assets and stocks.

(2) Motor transport insurance to cover loss or damage to the vehicle and liabilities to third parties.

(3) Employers' liability insurance in respect of industrial accidents to employees.

(4) Public liability insurance, *i.e.* liabilities to third parties arising out of the company's operations.

(5) Engineering insurance.

(6) Marine insurance on purchase of plant and equipment from source of supply to site.

And for those companies whose operations embrace ocean transport and inland distribution:

(7) Marine insurance on vessels, including shipowners' liabilities, *e.g.* liabilities for damage done to other vessels and to fixed objects, personal injury and crew liabilities, and carriers liabilities towards cargo owners.

(8) Marine insurance on cargoes in transit by sea or by inland waterways.

The broad principles of each of these main classes of risk and alternative methods by which the insurance needs under each heading may be met, are set forth in the following notes:

(1) *Fire and Explosion Risks on Shore Assets and Stocks*

A fire policy is a contract of indemnity, and any loss or damage by fire is reimbursable to the extent of the cost of making good the damage, but not exceeding the value of the building or plant at the time of the fire.

Generally speaking, plant and equipment utilized in

the oil industry is maintained to a high standard, not only for economic reasons but also to fulfil the need for ensuring high standards of safety; book values do not therefore provide a proper basis of valuation for insurance purposes. The most satisfactory basis is replacement cost—which must be kept under constant review—subject to deduction for depreciation or wear and tear only where there is a high rate of obsolescence.

There are varying methods by which physical assets may be insured against fire and explosion risks. It might suit the needs of the organization to have an itemized schedule of its assets with the insurable valuation of each item, and to insure those assets in their entirety. An alternative method is to establish an overall valuation and insure on a "first loss" basis, whereby a limit is placed on the total amount recoverable for any one loss based on an estimate of the maximum potential liability. This is practicable and economical only where the schedule of properties is not only substantial in aggregate value but also divisible as to individual areas of risk. Yet another method, which is not acceptable to all insurance companies, is the "excess of loss" insurance, which provides recovery for losses in excess of a stipulated figure at any one event.

Stock-in-trade does not present serious problems. Market value is an appropriate basis upon which insurance should be taken out, and to meet the fluctuations in quantities in storage from time to time an adjustable form of insurance is generally used whereby the premium is payable only on the actual stocks at risk. It can be associated with the insurance of the corresponding physical assets should a "first loss" or "excess of loss" form of cover be desired.

Loss through the destruction of assets and stocks by fire or explosion is not necessarily measured in terms of the cost of making good the loss. The indirect results of a fire can have an equally serious effect upon the revenue in the form of interruption of work, increased cost of working, or loss of profits. Insurance can now be taken out for what is usually termed "consequential loss" to cover any or all of these resultant losses, and is particularly appropriate to the concern whose operations are of a concentrated character, where serious disruption of operations cannot be offset by increased throughput elsewhere. The larger groups, whose interests are widespread, can more readily adapt their needs to meet the misfortune of a serious fire by reason of their flexibility, and can thereby minimize the financial consequences.

(2) *Motor Transport*

With the development of the motor vehicle as a form of transport has grown the need for providing suitable financial security to the innocent victims of road accidents. In most countries throughout the world legislation now exists whereby all owners of motor vehicles must effect insurance against third party personal injury risks with approved insurance institutions before licence is granted to use the vehicle on the public highway. Insurance of some kind or another for motor vehicles is therefore almost universal. A comprehensive motor vehicle insurance provides protection for loss or damage to the insured vehicle as the result of fire, theft, or other accident associated with third party cover for injury to persons and damage to property.

Owners of large fleets of vehicles, particularly those who maintain their own repair facilities, might choose to insure third party risks only, or third party and fire risks, leaving accidental damage risks uninsured. In this event consideration must be given to the question of processing claims for own vehicle damage against the wrongdoer, a service normally undertaken by the insurance company where insurance is on a comprehensive basis.

(3) *Employers Liability Risks*

In most countries today legislation exists which entitles an employee or his/her dependents to compensation, in accordance with prescribed scales, for death or bodily injury as the result of accident whilst at work. Superimposed upon this entitlement to compensation, the laws of the country sometimes stipulate that employers must effect insurance to provide for their liability under Employers Liability or Workmen's Compensation Acts. To meet this situation insurance companies have developed suitable organizations not only to provide the required insurance protection but also to handle claims, and this service is of particular benefit in cases of serious accident which might lead to dispute between employee and employer.

Where industrial accidents have been absorbed into State social security schemes—this is so in the U.K., for example, but not in the U.S.A.—workmen's compensation insurance as such ceases to be a subject for private insurance. The State insurance scheme does not, however, deprive the employee of the right to claim against the employer at common law where there is negligence on the part of the employer or on the part of a fellow worker.

The peoples of industrial nations have become much more claims conscious in recent years with a resultant increase in the number of claims at Common Law and at the same time a substantial rise in the size of compensation awards. Common law liabilities as between employer and employee form part of workmen's compensation insurance, but in countries where the State has assumed responsibility for industrial accidents under social security schemes these liabilities which can involve an employer in substantial claims, should be insured notwithstanding the provisions of State insurance schemes.

(4) *Public Liability Risks*

In every sphere of operation in the oil industry there is, in one form or another, a potential liability towards third parties for injury to persons or for damage to property which may be attributed to the negligence of

the company, or of its servants, or to defects in its plant and equipment. This is fundamentally a common law liability.

For the operation of transport, such as motor vehicles, ships, and aircraft, there are specialized forms of insurance which provide protection against liabilities of this kind, but for general shore operations, such as those associated with ownership of refining and distribution properties, it is prudent management to seek protection against public liability risks by way of insurance.

The negligent acts of shore employees in the course of loading or discharging ocean-going tankers might well involve serious damage to the ship and other shipping in the vicinity, as well as loss of life, and with the increasing use of super tankers the liability can be very substantial in amount. Similarly, although to a lesser extent in amount, the operation of inland depots and service stations exposes those engaged in the industry to serious financial loss should there be damage to surrounding property or injury to personnel as the result of fire or explosion, or other circumstances.

(5) *Engineering Insurance*

This class of insurance is not universal, although it has developed very considerably in the U.K. as the result of legislation passed from time to time imposing upon those engaged in industry an obligation to undertake periodical examination of certain types of equipment, such as steam boilers and lifting tackle. The legislation provides that the required periodical examination must be undertaken by a competent person, and as a result certain insurance companies have developed specialized branches employing qualified surveyors to undertake on behalf of the operator the inspection requirements of the relevant legislation; in association with this inspection service a measure of insurance protection is provided against explosion of boilers or breakdown of plant and liabilities to third parties arising therefrom. The extent to which the services of an insurance company's surveyor should be used to undertake this statutory inspection of plant depends to a large measure upon the technical services available within each oil company's own organization.

By reason of these statutory inspection requirements in the U.K. the ordinary forms of fire and third party insurance exclude explosion of vessels subject to internal steam pressure which necessitates a separate boiler insurance to provide insurance against damage to the plant and third party liabilities resulting from explosion or collapse, including the periodical inspection service required by legislation.

(6) *Marine Insurance on Purchases of Plant and Equipment*

Exploration, production, and the ensuing phases of operation, *i.e.* refining and distribution, involve a substantial and continuous purchasing programme for the supply of plant and equipment. This usually involves sea transit in the course of conveyance between source of supply and site, with the resultant need for marine insurance coverage, unless the purchase contract is on c.i.f. terms, in which event the supplier would assume responsibility for insurance and delivery to destination. The general practice amongst oil companies is, however, to purchase either *ex* suppliers' works or f.a.s. at port of loading and to make their own freighting and insurance arrangements. To meet these continuing insurance needs it is advisable to obtain an annual contract whereby all shipments are automatically covered up to a prescribed maximum any one vessel, subject to declaration of all shipments as they are made.

The standard form of marine policy on cargo affords protection against the total loss of the insured interest by perils of the sea and only very restricted cover in respect of partial loss. It also covers the cargo owners' liability for contribution to general average and salvage charges (these aspects of marine insurance are more particularly dealt with in the following section under the heading Marine Insurance on Vessels).

It may be noted that marine insurance in the U.K. features on the Statute Book, and the Marine Insurance Act 1906 defined in some detail the proper interpretation of the marine insurance policy, whilst case law has still further clarified the position of the insured *vis-à-vis* the insurer.

The standard form of marine policy is usually modified by the adoption of clauses recognized in the marine insurance market. Those in common use are either free of particular average clauses or with average clauses, whilst on occasions materials are insured on all risks conditions. It should be pointed out that whilst free of particular average clauses provide only a slight refinement of the standard policy form, the with average clauses widen the conditions to include partial damage resulting from all perils of the sea, including the elements; the scope of the all risks type of policy is obvious, although it does not include damage resulting from the natural quality of the subject matter insured, nor loss resulting from delay.

The needs of each individual oil concern depend to a large extent upon the volume of traffic and the nature of the plant and equipment, although it is generally considered sufficient to cover only the major perils by insuring on the basis of the free of particular average clauses mentioned above.

(7) *Marine Insurance on Vessels*

Almost every major oil company is concerned in one way or another with the operation of ocean-going tankers, as a large part of the world's tanker fleet is owned and operated by units within the oil industry. In addition to the huge capital investment involved in the acquisition of tanker fleets, the ownership and operation of this kind of asset involves risks and liabilities which are much more complex and completely different from those associated with the ownership and operation of shore assets.

Assets afloat are exposed to all the perils of the sea in addition to the risks of fire and explosion, including the liabilities associated with maritime law, such as general average and salvage; liabilities for damage done to another vessel in collision and for damage to fixed objects; personal injury liabilities resulting from collision or other casualty; liabilities towards the crew; and liabilities as carriers towards cargo.

It is of interest to note in relation to the expression "General Average" that one of the earliest remnants of ancient maritime law deals with jettison made for the sake of saving ship and cargo, and with the manner in which loss arising out of such jettison shall be treated. From this has grown maritime law as it is practised today, whereby all loss which arises in consequence of extraordinary sacrifices made, or expenses incurred, for the preservation of ship and cargo shall be treated as general average to be borne proportionately by all who are interested in the venture. General average is not therefore in any way dependent upon insurance for its existence; there is a liability of cargo owners and shipowners to one another for general average contribution quite independently of the insurance contract.

The term "Salvage" is used to denote a service, rendered voluntarily and not as a duty, that helps in saving from peril a vessel or any property that has been involved in a marine adventure. For such service an award in the form of money is given out of the value of what property is saved. The term "Salvage" is used to signify not only the "doctrine" but also the "award." The right to claim this award has grown up under maritime law, and is peculiar to it in that there is no such right for the preservation of property on land, the object being to encourage such services in the peculiar nature of sea conditions. Salvage includes also the saving of life from a marine adventure, but an award for so doing can be claimed under maritime law only if property also is saved, and only out of the value of the property.

The basic insurance needs in relation to the ownership of vessels are therefore, first, a marine insurance policy, preferably on full conditions, or if desired with the more restrictive conditions which are available, and, secondly, an entry in one of the protection and indemnity associations to cover the liabilities incidental to shipowning other than for damage done to another vessel in collision.

A marine policy on full conditions would cover total loss of the vessel as a result of a marine casualty; damage to the vessel as the result of fire, collision, stranding, heavy weather, or other peril of the sea; also liability for damage done to another vessel in collision, and for contribution to general average and salvage. The liabilities incidental to shipowning, such as loss of life and personal injury claims, damage to fixed objects, liabilities towards the crew, and liabilities as carriers of cargo, fall within the scope of the cover afforded by the protection and indemnity associations referred to earlier in this paper.

With the high cost of shipbuilding today and the increasing size of modern tankers, particularly those used for the carriage of crude oil from the producing areas to refineries, the total loss of a ship can have serious financial consequences, and to the same degree a serious casualty, possibly involving another ship in collision and even salvage (for which service the award is related to values), may prove costly. In consequence, the premium outlays for the insurance of vessels represent a large proportion of the insurance costs of a composite oil group. It is possible to minimize these premium outlays by insuring only against the major perils and liabilities, while there is a tendency amongst the major groups to adopt a measure of self-insurance in this respect. Reference to this aspect of insurance in the oil industry will be referred to later in this paper.

(8) *Marine Insurance on Oil Cargoes*

The transport of oil from the source of production to the country in which the ultimate products are to be distributed, with possible intermediate transit to a refinery, involves a considerable volume of ocean transport, and the insurance requirements depend to a large extent upon the basis upon which the supplies are shipped.

Composite groups who are shipping crude oil from producing areas to their own refineries, and in turn from those refineries to the distribution areas, will require marine insurance protection for at least the replacement cost of the oil, and freight if incurred. Where sales are made from one company to another there may be differing terms of supply, *e.g.* f.o.b. vessel at loading port, or c. and f., or c.i.f., but whichever method of supply is adopted one party or the other needs to consider some form of marine insurance of the cargo against total loss and partial loss as the result of perils of the sea, including coverage for liability as cargo owners for contribution to general average and salvage, referred to above.

As with cargoes of plant and materials, it is possible to insure on full conditions, or on the more restricted conditions known as Free of Particular Average, according to the needs of the individual concern; but if full protection is needed the insurance should expressly include leakage, shortage, and contamination losses in excess of a stipulated percentage. The individual requirements depend to a large extent on the volume of traffic; if the volume is substantial it should be sufficient to confine insurance to the major perils as covered by a policy on free of particular average conditions.

This broad survey of the main classes of insurance would not be complete without some mention of the other risks to which those engaged in the oil industry are exposed, and the related insurance facilities:

Embezzlement of Funds

There are some concerns who consider it desirable to secure protection for this kind of risk—usually termed fidelity guarantee—and for the loss by robbery or theft of monies in transit, particularly in relation

to the periodical drawings of cash from the bank for the payment of wages.

Miscellaneous Perils in Relation to Assets and Stocks Ashore

This envisages the violence of the elements, *e.g.* storm and tempest. Local conditions govern to a large extent the insurance practice, *e.g.* it is customary for companies in the U.S.A. to obtain, in association with a fire and explosion insurance, what is termed "extended coverage." This includes windstorm and the risks of riots and civil commotions. In the U.K., however, it is not common practice to extend a fire policy in this way, although the risks of riots and civil commotions can be associated with fire insurance. As a further example of special practice governed by local conditions, earthquake insurance in New Zealand is compulsory.

War Risks

It had become apparent before the outbreak of the second world war that war damage in relation to assets and stocks ashore was no longer a subject for insurance by private insurance institutions. The magnitude of war perils under modern conditions of warfare have so increased the chances of wholesale destruction that insurance by ordinary means could not possibly provide a sufficient fund to meet the possible consequences of war. Thus it has become a national problem involving suitable provision by individual governments whereby in time of war there can be restoration of essential services and facilities, leaving general rehabilitation to be dealt with according to the financial resources available.

The position in regard to ships and cargoes is somewhat different because the risk is a measurable one. During the second world war private insurance facilities continued to be available for ships and cargoes, but government war risks schemes were developed to supplement those private insurance facilities, and a greater stability of premium cost was thereby achieved. At the present time it is still possible to insure ships and cargoes with private insurance institutions, but in certain countries government war risks schemes are in readiness for implementation in the event of outbreak of another war. For example, British shipowners are able to insure their vessels through mutual war risks associations against a re-insurance agreement with H.M. Government which comes into operation in the event of an outbreak of war.

Construction Risks

The liabilities and insurance responsibilities in relation to the erection of refineries, storage installations, and similar large projects, also the building of new vessels, are usually expressed in the building contract. Broadly speaking, the terms are such that the contractor, or the shipbuilder as the case may be, assumes this responsibility and must maintain insurance in joint names to the satisfaction of the purchaser throughout the period of the contract. Suitable protection can be obtained for risks of this kind by contractors' indemnity insurance covering damage to works and plant, and third party liabilities in the case of shore risks; and marine insurance with shipbuilding risk clauses covering virtually all risks of loss or damage in the case of vessels under construction.

INSURANCE EXECUTIVES

Insurance in one form or another is an essential requirement of all business enterprises, but its degree of importance to individual undertakings varies according to the nature and extent of the operations involved. Generally speaking, however, those engaged in the oil industry operate under conditions that were scarcely dreamed of a few years ago, and the magnitude of their interests and the vital need for ensuring that the financial resources are not seriously impaired through fire, explosion, or other casualty suggests the importance of insurance as a sphere of operation within the orbit of each company management.

For the smaller concerns it may be sufficient to assign insurance responsibilities either to the secretary or to the accountant, who should look to brokers for specialist advice. In the case of the larger undertakings the practice of assigning insurance responsibilities to an already overburdened company official, such as the secretary or the accountant, has become outmoded, and it is not unusual to look upon insurance as a specialized field of activity demanding the services of a full time insurance executive heading a separate department as part of the overall management structure.

The insurance executive must be able to obtain physical and operational data relative to his company's activities, for there is no phase in the operations of those engaged in the oil industry—exploration, production, refining, shipping, distribution, sales, purchasing, construction, or personnel—that does not involve some sort of insurance problem. The procurement of this information depends entirely upon the degree of liaison maintained with other departments, and to ensure that the liaison is complete the insurance department should have full departmental status.

Accepting these basic principles, the insurance executive should assume full responsibility for maintaining an up-to-date record of insurable values of assets; considering the risks to which those assets are subject and the liabilities associated therewith; undertaking an analysis of those risks; developing an insurance programme best suited to the risks involved in relation to the resources of the company; and negotiating the required insurance contracts.

A properly trained insurance executive should be able to deal with these various problems without depending solely on the advice of brokers, for while the broker plays an important part in the business of

insurance, generally speaking the broker is employed to use his contacts in the insurance market and his general business knowledge to obtain the required insurance protection in the most satisfactory and economical way.

Nevertheless, it is just as essential for the insurance executive to establish general contacts with those engaged in the business of insurance, *i.e.* brokers and insurance companies, as it is for him to maintain a proper degree of departmental liaison within his organization if he is to ensure that his company's interests are fully safeguarded from the insurance point of view. Where the interests are world-wide it is necessary also to keep in close touch with local legislation, which may affect the liabilities of the company or the manner in which the insurance arrangements may be carried out. Additionally, centralization of the insurances of a world-wide concern should prove economical, although in some countries today currency laws and the desire to foster national insurance institutions have a restrictive effect.

INSURANCE PROGRAMME

It has been remarked that if every possible hazard that exists in relation to the assets and operations of a company were insured the premium cost would constitute a heavy first charge on the Company's resources. Thus, in the process of developing an insurance programme it becomes necessary to exercise a degree of selectivity in the risks to be insured and those to be left uninsured. This selectivity may be exercised in a variety of ways. It will have been noted from the broad outline of the main classes of insurance that there are differing conditions of insurance for individual classes or risk, some more comprehensive than others. There can be a degree of selectivity in this regard. On the other hand, it may be felt that certain assets or risks may be left uninsured.

Where, however, the financial resources allow and the interests are sufficiently widespread, a system of self-insurance may be adopted. This is a practice which has developed during the last few years amongst the larger industrial undertakings and involves the creation of an internal insurance fund to deal with selected risks. Such a system can justify itself only if it is kept under close control by the insurance executive in association with the normal insurance activities of the undertaking, and supplemented by external insurance coverage to meet the consequences of catastrophic loss. It is in this direction that many major industrial undertakings today are turning to the insurance market for their insurance coverage.

CONCLUSION

In this paper an attempt has been made to provide a basic background of insurance in the oil industry. Insurance is a means of securing financial protection, but prevention is as important as protection, for it will be readily appreciated that there is a definite relationship between the cost of insurance and losses. Oil as a commodity is in itself dangerous unless it is handled in accordance with generally accepted safety standards, and there is due observance of those safety standards by both employer and employee—more often than not losses are attributable to the human element, *i.e.* the result of acts or omissions of individuals. Thus, although insurance is a means of providing reimbursement of financial loss as the result of fire or other casualty, any loss, however caused, whether it be recoverable by way of insurance or not, is a form of wastage, and it is only by constant watch over the company's loss experience by the insurance executive that this form of wastage can be kept to a minimum, with resultant benefit to the company's financial structure.

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DISCUSSION

H. Chamberlin: The paper we have just heard dealt with a vast field. It showed us how insurance has served industry from the earliest days, how it has developed, and how it is still developing to give those same services it has always given. In doing so, it must hold the balance fairly between each individual industry and the whole body of industry; not just in one country but world-wide. Mr Wright has dealt with all aspects of insurance and its services to the industries of the world, as well as to the oil industry. Tonight we are most concerned with insurance and the oil industry, and whether they are working well together for their mutual benefit.

In the first place, I would like to look again at the famous definition of insurance which Mr Wright quotes and which was drafted in a statute for the first Queen Elizabeth by Sir Francis Bacon. The definition is "Insurance is a means of spreading loss, so that it lighteth rather easily upon many than heavy upon few, and rather upon them that adventure not than upon those who do adventure." The word "adventure" is used here in its best sense which is so typical of the first Elizabethans, but we claim it is equally true of the men in the oil industry today, who "adventure" to such purpose that the industry has become a "giant" which is a challenge to its ancillary industries, such as insurance.

Insurance is an ancient and firmly established institution. It seems to me that it works rather in the same way as the Japanese doctor, who some of you may have heard about—I understand that formerly the plan was that you paid the doctor when you were well, so that he treated you free when you were ill. Insurance does something like that. It takes your money by way of a small but regular fee when you are well, and pays you your losses when you are hurt. Like the doctor, it has you on its card index. In topical language, it keeps the score, the batting and the bowling averages of the indus-

try. It is a kind of "weather man," except that it is prepared to back its own forecast with its own money. It says, "Prepare for losses, maybe large ones, which may hit any one of you. We can not say when, or to what extent, but sooner or later there is going to be a loss. So certain are we of this, that for those of you who pay for our services, we will, so far as money can do it, make good your loss."

Insurance is a good listener. It says to the oil industry "Tell us about yourself. Let us have a look at what you are doing. What are your risks, and what are your defences against the old enemy, fire? We know him! He is a waster on the grand scale. Let us look at the "score." Today he is costing the U.S.A. $900 million annually, and the U.K. £25 millions sterling. How are you faring at sea? Let us look at the "score" here, too. We are most interested in your own special ways of transporting your products. Prove to us that they reduce the "score" of losses, and we will reduce premiums proportionately.

Mr Wright drew particular attention to the special risks of the oil industry, and the new perils with which oil has to deal, which arises from its nature. It is a dangerous liquid required in vast and increasing quantities. Originally oil risks were insurable only at higher rates than other industries, because of the obvious hazards and lack of experience. But oil is a competitive industry, and it learns fast. What has it learnt? I suggest that it has learnt at least four things from insurance.

> *First*, that losses do not happen; they are caused.
>
> *Secondly*, what are the likeliest causes? Lack of care and foresight. For instance, oil cannot burn except in air, therefore keep it away from air. Hence the development of pipelines, bulk storage, and bulk transport, all of which are so familiar today, but all of which have been developed in our own lifetimes.
>
> *Thirdly*, spread your risks physically, as well as financially. For instance, space out your oil tanks and your refinery plant, protect your key units and put them in places at a safe distance from danger points.
>
> *Fourthly*, keep your own "score" and always strive to improve your "average."

The oil industry has learned so much about its own risks in the hard school of experience, and has so improved its methods and reduced the "score" of its losses, that it compares favourably now with any other industry, and often pays the lowest premiums where it used to pay the highest.

Mr Wright mentioned the large capital investment in the oil industry. This large capital investment, the high values and variety of the tools of the oil trade, more and more compel simplification of insurance data and premium rating. Here the insurance industry has readily accepted data in short summary form instead of in detail, and flat average rates, rather than a range of varying rates.

However, the aspect of Mr Wright's paper of most interest is this question of selection of risks which are to be insured or not insured. The process of working together by the oil and insurance industries is a very real one, and they have a mutual interest in saving on the costs of risk bearing. Insurance can effect a saving on this cost only down to the point of the actual average loss plus the insurance service charge. Often this is mutually satisfactory both to the oil and insurance industries. Sometimes, however, the oil industry considers that it can effect a further economic saving by deliberately running a calculated risk uninsured. This is where selection comes in. Experience and judgment, both of oil and insurance, is essential. One proceeds cautiously always and selects comparatively well-tried risks, *e.g.* normal risks on material stocks and transports where no high concentrations of value are involved. In time, however, the process of selection, particularly if developed on a basis of mutual selection, results in the whole field of insurable risks being divided something as follows:

> The oil industry itself bears unaided those losses which, in its experienced judgment, are suitable to carry and which do not occur irregularly or with violent fluctuations.
>
> The oil industry insures fully or to a major extent those other losses, which occur irregularly and which can amount to such large sums as to threaten even the biggest companies so seriously as to curtail their activities.

The question I would like to put to Mr Wright and which will open the discussion is what our American friends call the sixty-four dollar question, namely: Does the oil industry's present position, by which only selected oil risks are insured, arise more from the comparatively heavy cost of a full insurance programme, or does it arise more from the internal strength and highly developed organization of the oil industry, which enables it to bear uninsured and without inconvenience a carefully selected share of its own risks?

A. T. Wright: Mr Chamberlin's reference to batting and bowling seems to suggest the Ashes, which also suggest a fire, and a fire should result in some insurance recovery. I suppose that is the chain of thought.

Mr. Chamberlin said that oil has learnt from insurance, but insurance has also learnt from oil, and the experience gained is mutual. Equally, insurance learns from other industries, and other industries are in some way or other indirectly related with oil, because the oil industry has its ancillary undertakings; so I venture to suggest that insurance, as such, and the experience of the insurance market behind it can provide a very great service to all those engaged in the oil industry.

First, I would like to correct any false impression I may have created on this subject of selection.

I do not see how one can get down to a basic cost of insurance to the extent so clearly defined by Mr Chamberlin, unless one takes the insurance claims cost over a wide range of concerns both within the industry and without, rather than those of an individual company or group. Let us take as an example insurance of ships. One could not base one's considerations on a few ships, say twenty or thirty or so, and assume that because losses over a period of two or three years amounts to £*x* per annum, therefore insurance costs should be £*x* per annum plus, when, because of the unpredictability of the elements, there is always the possibility of serious loss. Therefore I would say it is a question of degree when approaching the problem of selection of risks to be insured or not insured.

To reply to Mr Chamberlin's sixty-four dollar question: "Does the oil industry's present position, by which only selected oil risks are insured, arise more from the comparatively heavy cost of a full insurance." I would say, "No." Again, it is a matter of degree. I would not say that the cost of insurance is heavy on oil risks, because in the course of years, as the result of experience, insurance companies having learned from the industry and vice versa. Premium rates have been steadily reduced until oil installations and refineries can now be insured at a rate which almost corresponds with that for a private dwelling house. I would say that the fire risk on a building containing general stores probably presents a greater hazard than the insurance of a refinery today.

We come then to the alternative question: "Does it arise more from the internal strength and highly devel-

oped organisation of the oil industry, which enables it to bear uninsured and without inconvenience a carefully selected share of its own risks? I think the answer lies mainly in the extent that risks are spread. A newly developed concern or one with its risks concentrated would not be wise in applying too much selection in the risks it should insure and what it should not. The management of every concern has its shareholders' interests to consider, and insurance against fortuitous loss is essential for the security of the company and, in turn, its shareholders. Therefore, the obligation of the management is to ensure that the assets, stocks, and all the liabilities to which the company is exposed are protected by way of insurance, and that measure of insurance is determined by what is known of the risks involved. In turn, one develops one's thoughts along the lines that small risks which are well spread might be selected for a system of internal insurance or no insurance at all, always associated with a degree of control. One must exercise caution in applying a system of internal insurance in any event, and watch carefully the effect of losses on the financial structure of every concern. I think therefore the answer to Mr Chamberlin's sixty-four dollar question is that the selection of risks and perhaps a system of internal insurance arises more from the internal strength of the highly developed organization of the oil industry, always having regard to the extent that its risks are spread. Insurance implies that losses are spread amongst the community, therefore you must have your risks well spread if you are to select risks for insurance.

A. M. Pirie: Mr Wright has drawn attention to the Elizabethan description of insurance as a method whereby risks may be shared among the many rather than borne by the few. He has also said that there is a tendency among major groups to self-insure. Is not the notion of self-insurance in contradiction to the previous description of insurance as a system whereby the many rather than the few bear the risks? Is there not an internal contradiction in the use of the phrase "self-insurance"? If there is not, how does an internal insurance fund differ from an ordinary financial reserve?

A. T. Wright: Self-insurance is not really a contradiction to the basic objects of insurance if you consider the other aspect, which was dealt with a few moments ago—the question of spread of risks. It depends upon how your risks are spread. Insurance, where risks are not spread, is much more necessary to the small concerns. I do not say that insurance is unnecessary for the big concerns, but if every risk and every asset were insured by a composite group or large undertaking, the tendency would be to pay out in premiums substantial sums annually, recovering only a prescribed percentage of those premiums by way of insurance claims on what I think the market calls "bread-and-butter" losses; in other words, the regular losses. The system of self-insurance is therefore designed to take care of these smaller losses, *i.e.* the "bread-and-butter" ones, and it can only be applied to those concerns which have sufficiently strong financial resources, associated with a wide spread of risks. I would not suggest that there is really any contradiction between the basic object of insurance and a selected insurance system or self-insurance of some kind.

E. Hine: I feel that we should stress to the oil industry the inherent obligations to shareholders concerning the length of the indemnity period they include in their consequential loss policies in the event of a serious catastrophe. Very often one finds in the insurance industry, that these indemnity periods are arranged for 6, 8, or 12 months, particularly short times when one considers the delays that can arise in reconstruction or replacement programmes, and this, I feel, is a point that needs stressing on occasions when insurance is discussed.

At the top of page 154 of the paper, there is the question of replacement of damaged property-plant, and I do not altogether agree with the author that these items can be replaced if indemnity is obtained at their written down value at the time of loss. If one insures on a replacement value basis then one is able to reinstate the plant on the basis of "new lamps for old," and this point appears to be lost sight of, because it states lower down in the text that "the most satisfactory basis is replacement cost," etc., "subject to deduction for depreciation." If one insures on a replacement cost basis, one should use the full replacement value of the installation plant or storage tanks, or whatever item of machinery is in question. A little further on in the text the author mentions "first loss" insurance and "excess loss" insurance, and I think it might be mentioned that the English insurance companies do not issue this type of cover.

A. T. Wright: In regard to consequential loss, I think it is practicable to go beyond 6, 8, or 12 months; I believe even up to two years, but one has to pay premiums accordingly.

To return to the question of replacement cost. A first class industrial concern insuring with reputable insurance companies, and able to establish that its assets are maintained at a very high standard, should be able to obtain a recognized basis of indemnity in the event of loss which has relation to the replacement cost.

First loss insurance is not an uncommon system on the Continent, I agree this is not so in the U.K. There is, however, a tendency amongst insurance companies to be a little more flexible than they have been in the past. In any event, first loss insurance can be a snare and a delusion—although I hesitate to call it that—because the premiums are assessed virtually in accordance with the risks which are being carried, and a first loss policy is designed to meet the maximum possible loss and removes only that upper strata of catastrophic loss; it very seldom provides a substantial reduction in the premium costs.

A. G. Watson: It did strike me as perhaps a remarkable coincidence that the points Mr Wright made in his excellent paper, not only in regard to the various insurances he described but also his points in relation to insurance programmes, executives, and organization generally in a major oil company, to a large extent correspond with the views held by my company, and its policy generally.

There are, however, one or two questions I would like to ask Mr Wright. I think we are all agreed that in a major oil company there must be selectivity of risks placed on the outside market. Mr Wright mentions in his paper that there is a general tendency today on the part of such major industries or companies to self-insure, supplemented by a form of catastrophic insurance on the outside market, may I ask what is Mr Wright's concept of such catastrophic insurance in relation to value, and the extent of such insurance?

Linked with a prudent desire on the part of major oil companies not to spend too much on insurance, is a tendency today to insure material loss against fire, explosion, etc., to an extent whereby the particular company would bear a fixed amount of any given loss, and the insurers the remainder. I believe there is opposition to such insurance from certain companies, as is rightly indicated in the paper. Can Mr Wright give any idea as to the possibility or probability of any relaxation of that attitude on the part of the companies concerned?

A. T. Wright: I think Mr Watson's questions are based on this general aspect of selectivity. He makes reference to self-insurance, and my remarks about insuring catastrophic loss. He mentions also insurance on an "excess" basis.

I submit that one is related to the other. If you insure on an "excess" basis you are really self-insuring that portion of your risks which come within the "excess," that is to say the maximum risk which you are prepared to bear in any one accident or loss.

The extent of self-insurance is, I think, a domestic matter for consideration by each individual concern. Some groups have their own internal insurance companies; some operate by means of specially established funds. To place risks with a properly constituted private insurance company, or even an internal insurance fund established on a reasonably scientific basis, is self-insurance as opposed to non-insurance. I strongly urge that the system of self-insurance should not be entered into too lightly, because it involves a great deal of care in selection and very careful control, and unless you know what the self-insurance is costing you by way of losses there can be a tendency if you carry your own risks for losses to prove greater than they might have been if you had not insured. I say this because insurance is, in itself, a system of control. It provides a means of keeping losses within reasonable bounds, and one has the benefit of specialist advice from outside interests too.

Mr Watson mentioned insurance of catastrophic loss. There is a limited market, it is true. For that reason a broker should be employed, for it is his business to find the market. The same remark applies to excess of loss insurance. I believe he is quite right in saying that insurance companies are not very ready at present to insure on an excess of loss basis, but I think it is reasonable to say that insurance institutions generally have moved with the times, and I think the time will come when this kind of insurance will be more generally acceptable.

G. Heseltine: I would like to ask Mr Wright a question about selectivity, particularly as it effects the producing end of the industry. Is it possible for him to indicate a few examples of what, in his experience, a major company would, or would not, insure? Is any insurance carried on, say, a producing well against a blow out or fire, or an offshore drilling platform against storm damage? Would it be possible for Mr Wright to indicate if any losses incurred at the incident at Rig 20 were covered by insurance?

A. T. Wright: I am not sure what the speaker has in mind when he talks of insurance on a producing well, Does he mean the money expended in sinking that well. or the plant which is superimposed thereon or in the vicinity?

It is possible to insure against the cost of extinguishing a fire, but it is not generally accepted practice to insure the cost of sinking wells. Some companies insure the drilling plant, or in other words the material assets in the vicinity of wells; others do not, but this is a case where selectivity can be rightly or wrongly exercised. I would not advocate the selection of drilling plant in the vicinity of a well as being suitable items not to insure just because the component parts are mostly of steel. That would be taking selection too far.

A. Winnard: I wonder if a few remarks could be made on the importance of flash point as a factor controlling insurance rates covering the fire and explosion risks of stored petroleum products. I believe it has been stated that insurance rates on different flash point grades are set on a sliding scale basis. However, the safe storage of products of lower flash point grades would appear to receive adequate attention, if only to meet local regulations. This, it seems to me, might prevent an increase in insurance rates for a low flash product. Is it borne out in practice?

A. T. Wright: Generally speaking, fire insurance premium rates on oil storage tanks and stocks contained therein are based according to flash points. I think this practice is fairly universal, but so much depends on the premium rating arrangements of individual oil companies. In the U.K., and in many countries overseas, the flash point subdivisions for premium purposes are below 73° F (22·8° C), between 73° and 150° F (65·6° C) and above 150° F, thus there is one rate for fuel oil, another for kerosine, and a third classification for aviation and motor spirit. It depends upon the basic activities of the concern and its insurance methods whether the system of segregation according to flash point is adopted or supplanted by a flat rate system—it is very largely a matter of individual choice. However, those three flash point headings represent the main basis of premium rating for oil storage risks.

D. Grout: Could Mr Wright enlighten us with descriptions of some typical catastrophic losses?

A. T. Wright: The catastrophic risk directly relates to the nature and the extent of the particular hazards or interests concerned. To take as an example refinery risks—there is the possibility of a fire spreading from one unit to another, not necessarily involving the whole of a refinery, but perhaps two, three, or more very valuable units of plant, and it has to be remembered that some modern refinery units cost upwards of £1 million each.

Another type of catastrophic loss is the liabilities arising from the operation of a refinery whereby damage is caused to ships alongside, or in the vicinity of the jetty. If the shipowners can find justification for making a claim against the refinery operator on the grounds of negligence or some defect in the refinery plant a substantial financial loss might result.

A third kind of catastrophic loss is that associated with the operation of ships themselves. It is not unusual for two or more vessels of one ownership to be in port at the same time. An explosion or fire which spreads to another might even involve other shipping, with possible liability on the owner of the vessel for the resultant damage.

C. F. Mason: Without wishing to go too much from the general to the particular, might I ask Mr Wright whether he has any view on the desirability of products liability insurance in so far as the oil industry is concerned?

A. T. Wright: If one is producing products for direct sale, there is definitely a liability arising from the sale of those products, and that kind of risk is normally associated with what I describe in my paper as Public Liability risks. It is not necessarily a part of such insurance, but it can be dealt with by way of extension, and it is very desirable to consider this factor.

A. G. Watson: What are your views on the incidence of employers' liability claims since the repeal of the Workmen's Compensation Act? I ask this question with particular reference to the growing tendency of claims arising from the negligence of a fellow-employee, not to say the latest startling development of employers seeking recoupment from the negligent fellow-employee through, I believe, the medium of their insurers.

A. T. Wright: There has been a marked increase in the number of claims made by workers against their

employers at Common Law. It is the natural consequence of the introduction of the State insurance scheme under which the employee does not lose his right to State insurance compensation should he elect also to make a claim against his employer at Common Law. The tendency is for claims to increase not only in number but also in amount. In the U.S.A., compensation awards five years ago were almost astronomic compared with what they were at that time in the U.K. I would not say they are now astronomic in the U.K., but they are certainly much greater today than they were about five years ago, and this decided tendency for the worker (which is general amongst peoples of industrial nations) to be claim conscious is a factor which every employer must consider. I advocate insuring liabilities of this kind.

Lt.-Col. S. J. M. Auld: One thing which has greatly impressed me is that both Mr Wright and Mr Chamberlin, and by implication other speakers, have indicated that the oil industry as a whole has gone a great distance to help itself in the matter of selectivity by the reduction of risk, especially fire and explosion risk, through their arrangements, their discoveries, and by means of their codes which have been developed and put into operation. This is a great credit to the engineers and chemists at fields and refineries and in shipping.

My own small contribution to the talk is therefore to refer to the big changes which have happened in respect of the handling of combustible liquid products. Some thirty years ago I was in the chair on a very different occasion from this, at a Court of Inquiry at Abadan, investigating a fire on a coastal tanker which had involved the loss of nine lives. It had not apparently been realized in laying down the regulations, which were otherwise very stringent, that kerosine under tropical conditions, if coming in contact with the ship's decks, would be brought immediately far above its flash point. The mid-day shade temperature at that time had been well over 115° F, and consequently the deck temperature had been well above the 160° F which has been mentioned. The engineer in charge, being uncertain that the joint between ship and shore had been well made, had it broken but was unaware that in the meantime the major control valve ashore had been opened. As a result, a stream of kerosine came out on to the deck, and away it all went. That kind of thing just can not happen now, and it is a great tribute to everybody concerned that it can not.

A vote of thanks was accorded with acclamation.

THE STRUCTURE OF LUBRICATING GREASES UNDER THE LIGHT MICROSCOPE IN RELATION TO THEIR PERFORMANCE *

By J. F. HUTTON,† J. B. MATTHEWS† (Fellow), and N. A. SCARLETT†

SUMMARY

Results are given of the microscopical examination of lithium and sodium soap greases in ordinary and polarized transmitted light at linear magnifications varying from 75 to 650 dia. The structures revealed can be related to the macroscopic texture of the greases, to storage hardening, and to their performance in ball-bearings. Microscopical examination can thus be of use in controlling the quality of greases in their manufacture.

INTRODUCTION

IT IS remarkable that little attention was paid to the study of grease structure by direct observation until the advent of the electron microscope. Since 1944 a number of workers [1, 2, 3, 4] have published observations made with this high-resolution instrument, but their findings have apparently given little impetus to work with the lower-power light microscope. The limitations of the electron microscope, which have been referred to in a previous paper,[5] are such that, although giving information concerning the structure of individual soap fibres, the instrument cannot provide much information on the way in which the fibres are arranged in the grease to build up the macroscopic structure. These fibres, the diameters of which are usually fractions of 1 μ, are not resolved in the light microscope, but in spite of this the instrument is quite satisfactory for observing the coarser structural features. Clearly, the two microscope techniques are complementary.

The main factor limiting the use of the light microscope has probably been the difficulty in interpreting the results obtained. In a brief review Klemgard [6] states that before 1936 he and others had shown the existence of soap crystallites in greases. However, the work was not pursued, and the next advance, together with the first published photomicrographs, was made by Farrington and Davis [7] in 1936. Using dark field illumination and linear magnifications up to 1000 dia they found a relationship between the texture of the grease and soap fibre length, and proposed that greases should be classified into four major groups. Gallay and Puddington [8] obtained similar results using ordinary and polarized illumination.

More recently, Brown, Hudson, and Loring,[9] and Courtel and Pons [10] have reported the orientation of soap fibres under conditions of light shear, obtained by spreading grease on a microscope slide or by squeezing grease between a slide and coverslip. Courtel and Pons have also indicated the usefulness of light microscopy in the control of grease manufacture.

In this paper an endeavour has been made to show the relationship between results obtained with the light microscope and those obtained with the electron microscope. A few examples illustrate the value of the light microscope in the development of manufacturing processes and the understanding of grease behaviour.

EXPERIMENTAL

The photomicrographs were taken with the Vickers Projection Microscope, made by Messrs Cooke, Troughton, and Simms Ltd. The normal method of specimen preparation was to squeeze a small piece of grease between a microscope slide and coverslip. The exact thickness of the grease film is not critical, but efforts were made to keep the thickness at about 20 μ with the aid of slides cut with a groove 20 μ deep. However, in some experiments, which are indicated in the text, the oil was removed with *n*-heptane or petroleum spirit of boiling range 65° to 95° C. In such cases either a film of grease spread on the slide was immersed in the solvent or a drop of a dispersion of the grease in the solvent was placed on the slide.

RESULTS AND DISCUSSION

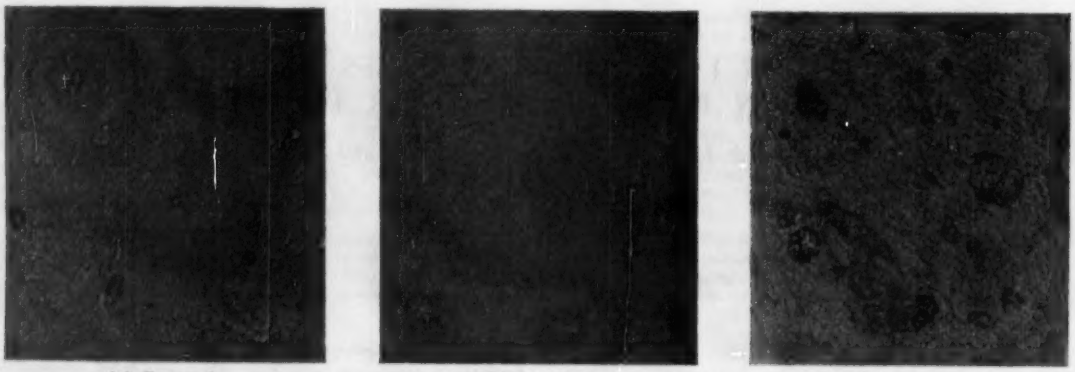
Texture and Structure

The Farrington and Davis classification [7] of grease texture appears to be supported by the results. Thus smooth greases such as those made from aluminium soaps and some made from lithium soaps contain very small particles, the largest of which are only just resolvable. Fibrous greases, such as certain sodium based greases, on the other hand, possess fibres as large as 200 × 10 μ. In the intermediate range a sodium-based grease with fibres up to about 30 × 1 μ was found to have a texture which can be described as slightly fibrous. This grease corresponds to the Farrington and Davis medium fibre or short fibre greases.

Any attempt to subdivide the four groups in this classification would lead to serious difficulties. It would not be sufficient to compare, as is done implicitly in Farrington and Davis' work, the maximum fibre size, but it would be necessary to compare an average dimension or even a size-distribution. This would involve measurement of fibres in both electron and light microscopes, since the fibre size range is considerable. In addition, a fibre dimension does not give a measure of "graininess" which contributes to

* MS received 2 November 1954.

† Thornton Research Centre.

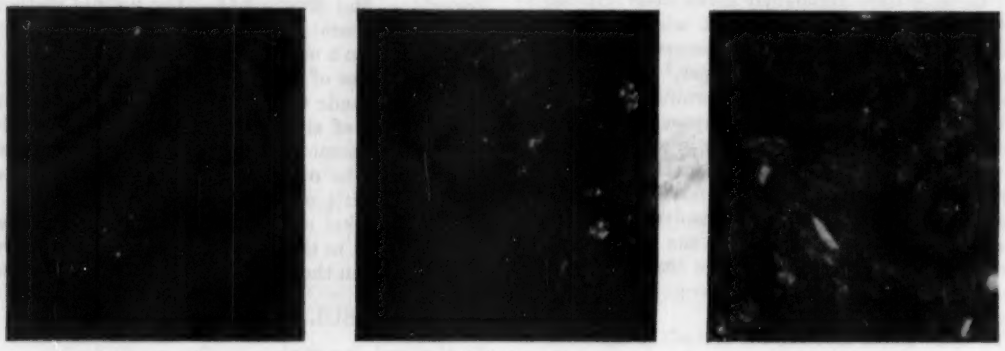


(*a*) Grease A (*b*) Grease B (*c*) Grease C

FIG 1

LITHIUM-BASED GREASES A, B, AND C. STRUCTURE AND TEXTURE

Heptane washed. Ordinary light. Original magnification × 325.

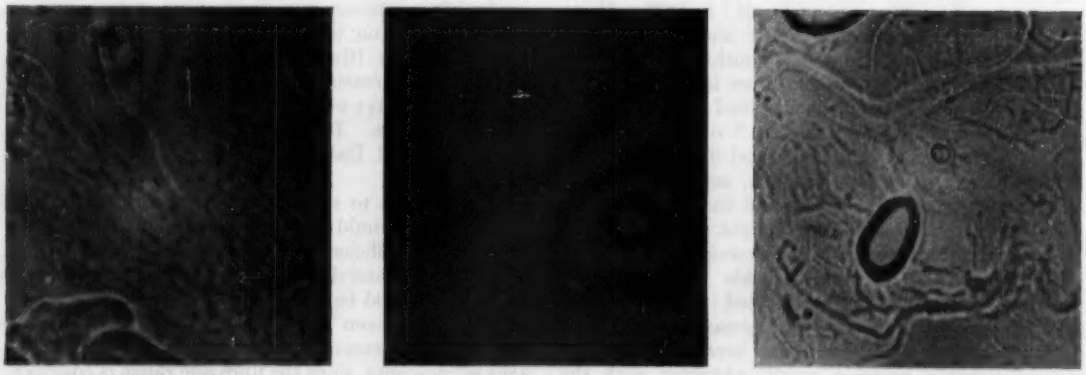


(*a*) Grease A (*b*) Grease B (*c*) Grease C

FIG 2

LITHIUM-BASED GREASES A, B, AND C. STRUCTURE AND TEXTURE

Polarized light. Original magnification × 178.



(*a*) Ordinary light (*b*) Polarized light (*c*) Ordinary light

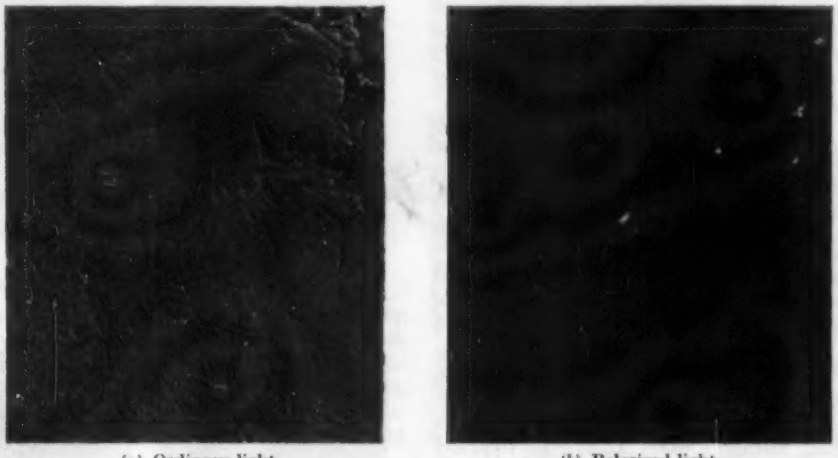
FIG 3

SODIUM-BASED GREASE D. STRUCTURE AND TEXTURE

Heptane dispersion. Original magnification × 650.

texture. Thus Fig 1 shows photomicrographs of lithium-based greases * after washing with *n*-heptane to remove the oil. The maximum fibre length does not differ very much from grease to grease, but the textures range from smooth (grease A) to rough (grease B) to very rough (grease C), and the tendency for the greases to generate excessive heat in bearings decreases in the order A to C. The rough texture arises from the presence of clusters of fibres, which presumably give the grease its grainy appearance. Fig 2 shows the same series of greases in polarized light.

On a macroscopic scale the distinction between fibrosity and graininess is not easily made, because when a piece of grainy grease is pulled from the bulk, the intergranular smooth material will be attached to each grain and thus give the appearance of fibrosity. Most greases contain soap crystal clusters or aggregates which contribute to the apparent fibrosity to an extent depending on their size and number. There is evidence that the very large fibres existing in sodium-based greases are themselves aggregates. In the electron microscope most of the fibres are smaller than those observed in the light microscope by a factor of 10 or more, but some electron micrographs show larger fibres which are striated and branched in a manner to be expected of aggregates. Light photomicrographs of the solvent-washed greases also show striated, branched fibres. It is difficult to bring into focus on a photographic plate the whole of a fibre or a number of fibres because the fibres are not coplanar. The appearance of fibres slightly out of focus is illustrated by Fig 3 (*c*). If the distance between the specimen and the objective lens is less than for the true focus the fibres assume an irregular outline and show irregular variations of light absorption along their length (lower part of Fig 3 (*c*)), but if defocusing is carried out in the opposite direction the lens action of the fibres themselves causes them to appear more uniform (upper part of Fig 3 (*c*)). The irregularities illustrated in the lower part of Fig 3 (*c*) suggest a fibre with a non-uniform cross-section, a condition which would obtain only if the fibre were an aggregate of smaller fibrils. Other evidence is obtained by studying a field of view in both ordinary and polarized light. Figs 3 (*a*) and (*b*) are of a fibrous sodium-based grease dispersed in *n*-heptane, whilst Figs 4 (*a*) and (*b*) are of the same grease washed in *n*-heptane so that the structure is disturbed as little as possible. The fibres in both cases exhibit regions having a higher crystallinity than adjacent regions. On rotating the specimen stage it is observed that the less-ordered zones do not become bright in polarized light. This variation of degree of order along a large fibre is an indication that the large fibre is an aggregate of smaller ones which in certain regions lie parallel to each other.



(*a*) Ordinary light (*b*) Polarized light

FIG 4

SODIUM-BASED GREASE D. STRUCTURE AND TEXTURE

(*a*) and (*b*) same field. Heptane washed. Original magnification × 325.

We thus conceive the following picture of the soap fibre structure of a grease. Soap crystallizes in the form of elongated fibrils which are resolved in the electron microscope. During the manufacturing process these fibrils aggregate together to form larger fibres, and fibres of various kinds can aggregate to form clusters. The texture of the grease is determined by the extent of aggregation. For many greases the aggregation can be studied with the polarizing microscope, since each crystallite represents

* The soap component of these greases was essentially lithium 12-hydroxystearate, the materials used in their preparation being identical for all three greases. The differences in texture were the result of differences in processing conditions.

a small volume in which the fibrils are aggregated in a high state of order. The permanence or strength of such aggregated structure is indicated by the absence of flow orientation. This phenomenon, referred to by Brown, Hudson, and Loring [9] and by Courtel and Pons,[10] is well illustrated by very smooth water-stabilized, calcium-based greases. The shear produced by squeezing the grease between slide and coverslip causes pronounced orientation of soap crystals in the direction of flow, so that the whole field of view in the microscope (which is a small region in which the flow lines are essentially parallel) appears similar to a single crystal. Thus, on rotating the specimen stage between crossed Nicol prisms there is found to be almost complete extinction at 45° from the positions of maximum intensity. In less smooth greases the effect is less marked, and rough-textured greases do not show this flow orientation, even when a film of grease is stroked in the same direction many times with a palette knife.

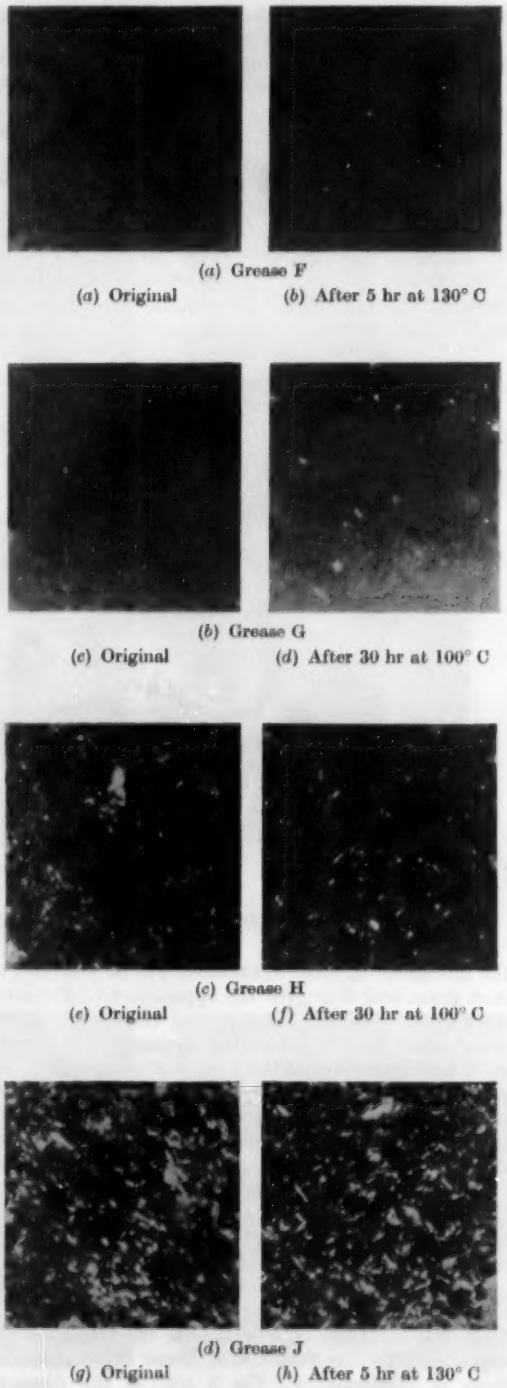
Storage Hardening of Greases

An undesirable property of some grease formulations is hardening in storage. This hardening, which is observed as a decrease in unworked penetration, is accelerated at elevated temperatures.

Fig 5 shows photomicrographs taken with polarized light at a linear magnification of 425 dia of a series of greases before and after static heating tests, in which the samples were worked as for the standard penetration test (IP 50/48), and whilst still in the test pots, stored at 100° and 130° C for certain periods of time. The greases are all made from the same ingredients, the soap being mainly sodium 12-hydroxystearate. Greases F and G were prepared by rapid chilling to room temperature of a solution of soap in mineral oil, whilst greases H and J were cooled more slowly with stirring. As indicated by the photomicrographs, greases F and G are smooth in texture, H and J are rough textured. After cooling from the storage temperatures of 100° or 130° C the smooth greases are very hard and tend to crumble under pressure, and on reworking change to a heterogeneous grease–gel system. On the other hand, the rough textured greases are only slightly harder than they were before the storage tests, and they easily work back to a uniform greasy consistency.

Table I illustrates the different hardening tendencies of greases F, G, H, and J, the change in consistency being the difference between the worked penetration (IP 50/48) of the original grease and the unworked penetration of the grease after the static heating test.

All the greases show little or no change in the light microscope as a result of the heat treatment. A possible explanation of the hardening phenomenon is that during storage cross-links form between elementary fibrils, at a rate depending on the mobility of the fibrils and on their availability. Thus, hardening is accelerated at higher temperatures, but it is decelerated if many of the fibrils are immobilized in the form of giant fibres and clusters. The maximum



(*a*) Grease F
(*a*) Original (*b*) After 5 hr at 130° C
(*b*) Grease G
(*c*) Original (*d*) After 30 hr at 100° C
(*c*) Grease H
(*e*) Original (*f*) After 30 hr at 100° C
(*d*) Grease J
(*g*) Original (*h*) After 5 hr at 130° C

FIG 5

SODIUM-BASED GREASES F, G, H, AND J. STORAGE TESTS AT ELEVATED TEMPERATURES
Polarized light. Original magnification × 425.

attainable hardening will also be smaller if the fibrils are highly aggregated in the original grease.

An additional conclusion which may be drawn from Table I and Fig 5 is that the structure, as shown by the crystalline aggregation in the microscope, does not correlate with penetration or hardness. This is supported by the results of observations of a large number of greases in the microscope over a period of many years.

TABLE I

Results of Static Heating Tests on Some Smooth and Rough Textured Sodium-based Greases

Grease	Texture	Penetration (IP 50/48) dmm		
		Original grease (worked)	Grease after static heating test (unworked)	
			30 hr at 100° C	5 hr at 130° C
F	Smooth	245	—	181
G	Smooth	223	158	—
H	Rough	247	296	—
J	Rough	282	—	253

Bearing Performance of Greases

The ultimate test of a grease is of its ability to give satisfactory performance in use, and one of the most important uses of grease is in the lubrication of anti-friction ball or roller bearings. In order to test greases for their suitability to lubricate a large number of different bearings, running under a wide variety of operating conditions, it is customary to select a bearing which according to experience is difficult to lubricate, and to run it at its maximum recommended speed under normal conditions of load and ambient temperature with the test lubricant. The bearing should then run normally if the lubricant is satisfactory. The bearing temperature should not rise too high in the first few hours of test, and should settle to within a few degrees of the ambient temperature during the first day or two of operation. The temperature should remain at this value for the whole remaining period of the test. During the test, loss of grease or oil from the housing is undesirable, and there must be no sign of wear, or chemical attack, or deposits when the bearing is finally stripped.

One of the rigs used in this work at Thornton Research Centre comprises a pair of 1¾-inch bore, deep-groove, ball journal bearings fitted with solid machined yellow metal cages located on the inner race shoulders. They are run at 4000 r.p.m. under no load other than driving belt tension acting at the centre of the shaft connecting the two bearings. No external heat source is applied. A standard procedure is used in applying the grease; the bearing itself is filled with grease, and the recesses in the end cover-plates are two-thirds filled with grease. The duration of a test is 500 hr.

When the rig is started the temperature of the bearing rises, owing to the work done in the redistribution of the grease throughout the bearing assembly. The displaced grease is deposited during this stage, both under the cage (where no grease is packed initially) in the form of pads and in the free space in the cover recesses. If the temperature is to fall the grease must remain stationary in the pads, relative to the moving cage, and in the covers. It has been found that this property of the grease, called by us " clearability," is related to the structure of the grease.

In the case of the lithium hydroxystearate greases mentioned above, the smooth grease A (Fig 2 (*a*)) has poor " clearability," and the bearing runs at an abnormally high temperature for the major part or all of the 500-hr test. Greases B and C (Fig 2 (*b*) and (*c*)), on the other hand, have good " clearability," and the temperature falls to a few degrees above ambient in a reasonably short time. Thus, for good " clearability " there is some evidence, in this grease system at least, that the grease should preferably have a rough texture.

Although it is possible to distinguish between the textures of these three lithium based greases with the unaided eye, this is not always the case. For example, the behaviour in bearings of certain sodium-based greases, made in conventional grease kettles from the fatty acids, was found to be more sensitive to changes in texture than in the case of lithium-based greases.

Fig 6 shows the appearance of a series of sodium-based greases in polarized light at a linear magnification of 75 dia. All these greases were made from portions of a single batch of a sodium-based grease by reprocessing in laboratory apparatus. In this way greases with different textures were obtained by suitable adjustment of the rate of cooling and of the total amount of stirring. It will be observed that, as one proceeds along the series K, L, M, N, O, P, the amount of crystallinity decreases progressively. Correspondingly, the texture changes, grease K being very rough, dry-looking, and rubbery to the touch, grease N being a short fibre grease with a slightly rough and oily appearance, and grease P being smooth and translucent. The rig performance of these greases falls into four main groups :

(1) Represented by grease K. These greases are expelled from the bearing very early in the test, and leak along the clearance between the shaft and the cover plate. This behaviour is called " winding out." The running temperature falls rapidly, and cage wear occurs soon afterwards.

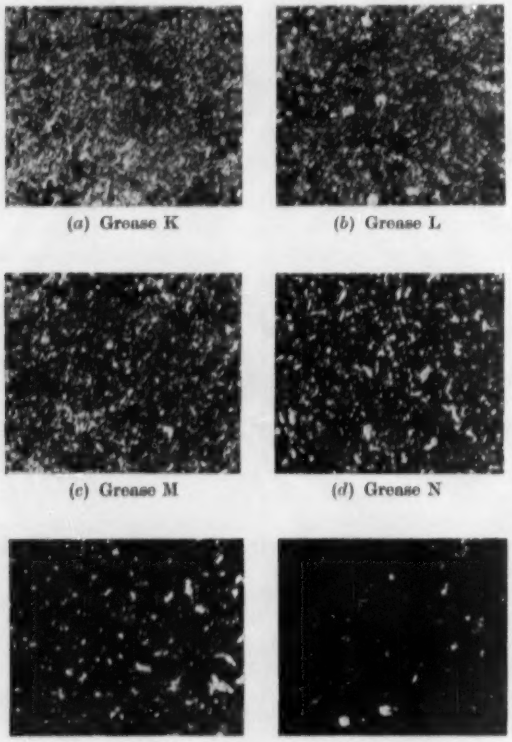
(2) Represented by greases L and M. In some tests there is a little grease loss due to " winding out." The greases have good " clearability " and the temperature falls in a short time. However, wear of the cage occurs within 100 to 400 hr.

(3) Represented by greases N and O. There is no " winding out." The greases have good

" clearability," and the running temperature falls in a short time. There is no wear after 500 hr.

(4) Represented by grease P. There is no " winding out," and the " clearability " is poor, so that the temperature varies erratically or remains at an abnormally high value. Sometimes there is leakage of softened grease at a late stage in the test, if the temperature is abnormally high. If the temperature falls, cage wear occurs soon afterwards.

Considering first the " clearability " as it affects the running temperature, we see that as the amount of crystallinity increases the " clearability " increases.



(*a*) Grease K (*b*) Grease L

(*c*) Grease M (*d*) Grease N

(*e*) Grease O (*f*) Grease P

FIG 6

SODIUM-BASED GREASES K, L, M, N, O, AND P. GREASE STRUCTURE AND PERFORMANCE IN BEARINGS

Polarized light. Original magnification × 75.

However, if the texture is too coarse and the aggregation results in a coherent, rubbery material, the grease separates too readily from the moving parts of the bearing. The grease is therefore unable to form pads under the cage, and the movement of the balls forces it into the free space in the cover plate recesses. These recesses, being of limited capacity, are unable to accommodate all the grease which tries to enter, and consequently " winding out " occurs. The other important aspect of the rig test is lubrication, and there is some indication that the texture is also related to the ability of the grease to lubricate the bearings. The tracks and balls of the bearing are relatively easy to lubricate, but it is more difficult to lubricate the rubbing surfaces formed by the bore of the cage and the shoulders of the inner race. The clearance here is very small, and the problem is one of plain journal lubrication. To avoid wear of the cage it is necessary for grease to penetrate between the surfaces. It is probable that, if the " clearability " is poor, so that separation of the grease from the moving parts is delayed or does not occur at all, the grease has a very good opportunity to penetrate between the surfaces. Conversely, if the " clearability " is very good, the grease may have no opportunity to penetrate between the surfaces.

Unfortunately, it is not possible to explain all the wear phenomena in grease-lubricated bearings in terms of " clearability " alone. For example, good lubrication can be obtained with greases which have good " clearability," as in the case of the third group of greases described above. Again, in the case of the fourth group of greases wear can start soon after the grease separates from the moving surfaces, even though separation occurs only after prolonged operation. Some other property of the grease, at present unknown, is obviously concerned in determining the ability of the grease to lubricate the bearing continuously. This property may be the ability of the lubricant left in the bearing to circulate slowly and continuously through the narrow clearance between the cage and the inner race. If the grease hardens excessively and irreversibly on being heated, such as is the case with the smooth sodium-based greases representing the fourth group, this circulation may conceivably be stopped.

GENERAL CONCLUSIONS

The basic units of structure in greases made from soaps are generally elongated soap fibrils, which are revealed in the electron microscope. Earlier work [4] has shown that the geometry (length–diameter ratio) of these fibrils can determine the consistency of the grease, but it seems clear from the results given in this paper that other important grease properties depend on the structure built up by the aggregation of the basic units.

A fibrous texture may be ascribed to aggregation of the fibrils into larger fibres, whilst a grainy texture apparently results from the formation of clusters of fibrils.[11] Experiments on the orientation of soap particles in flow indicate that the forces of attraction between fibrils in an unaggregated grease are weak compared with the forces that operate between fibrils in the aggregates.

At the same time, however, it would appear that under suitable conditions bonding can occur between the unaggregated fibres to give a continuous form of structure throughout the grease, which results in

hardening. This hardening appears to be of a less permanent character, and occurs to a smaller degree, as the proportion of free fibres to aggregated fibres decreases. The aggregated structure is conveniently studied with the techniques of light microscopy, especially with polarized light at relatively low magnification. It is evident, however, that for a complete study of grease structure both the electron microscope and the light microscope should be used.

Since for a given grease system the amount of crystallinity will probably vary inversely with the amount of free fibres, and flow orientation is apparently restricted to the free fibres, it follows that measurement of flow birefringence may provide a convenient and quantitative measure of the structure of the grease.

The results discussed in this paper show that, with the types of grease described, hardening in storage can only be avoided if the greases are made with a rough texture. Furthermore, a rough texture is desirable in these greases from the point of view of bearing performance. However, a texture which is too coarse can be disadvantageous, because such greases are not easily retained in the bearing. Hence, in the manufacture of these types of grease a compromise in texture must be sought. To assist in reaching this compromise and to control the manufacturing process the light microscope can be usefully applied.

It must be emphasized, however, that these conclusions should not be generalized and applied to other grease systems without experimental justification.

ACKNOWLEDGMENTS

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THE INFLUENCE OF VANADIUM PENTOXIDE ON THE HIGH-TEMPERATURE SCALING OF HEAT-RESISTING ALLOYS*

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INTRODUCTION

For economic reasons it is necessary for gas turbines in many applications, particularly marine and industrial use, to burn cheap fuels. Residual oils from the distillation process are the commonest fuel for this purpose. The ash content of residual oil is frequently about 0·03 per cent, although figures as high as 2 or 3 per cent have been reported, and when deposited on the hotter parts of a turbine this ash can lead to serious corrosion. Similar cases of oil-ash corrosion occur in other applications of residual oils. The compositions of oil ashes vary very widely, but it has been established that the corrosion of alloys in contact with the hot ash is frequently due to vanadium pentoxide or sodium sulphate, particularly the former, and a considerable amount of attention has been paid to the general problem of hot corrosion of alloys by these substances.

The first report of a reasonably complete investigation of the problem, including a comparison of the resistance of different alloys to a standard ash and to synthetic mixtures, was that of Schläpfer, Amgwerd, and Preis.[1] These workers showed that attack occurred only when the temperature was above the melting point of the ash, and concluded that the mechanism depended on the liquid ash destroying or preventing the formation of the normally protective scale. The presence of vanadates, which implies reaction between the ash and the metal oxide, was detected by X-ray analysis of the deposits. Tests with various mixtures of V_2O_5 and Na_2O showed that a maximum rate of attack on a 25 per cent chromium, 20 per cent nickel, austenitic steel at 850° C occurred with equal proportions of the two constituents, and it was thought that this was due to the formation of unstable sodium vanadate which liberated oxygen within the ash, and so accelerated the attack. It was noted that alloys containing molybdenum were particularly strongly attacked due to the volatility of molybdenum trioxide.

Essentially similar views on the mechanism of vanadium pentoxide attack were formed by Sykes and Shirley,[2] who carried out investigations on a number of heat-resisting steels with both pure vanadium pentoxide and synthetic mixtures simulating oil ashes. An interesting observation was that the rate of corrosion remained essentially independent of the V_2O_5 content of the ash until the content fell to 1 per cent. Ten different heat-resisting steels and alloys were compared in a standard synthetic ash at 750° C, and while differences in corrosion rate covering a range of more than 1–10 were observed, the significant variations in composition leading to these differences were not clear. The use of chromium plating or chromized coatings was investigated, but neither treatment provided very useful protection.

The most comprehensive investigations yet reported are those of Evans,[3] who compared as many as eighty different materials or protective coatings. The tests were carried out by partial immersion of the samples in powdered ash, and heating of the assembly to the test temperature of 732° C for 168 hr. The degree of attack was qualitatively assessed by visual inspection, and it was concluded that no material could be considered completely immune to attack by the high-vanadium ashes used for these tests, but that the alloys with the best corrosion-resistance had the poorest high-temperature mechanical properties. Furthermore, low-nickel or nickel-free iron-base alloys were more resistant than high-nickel or cobalt-base alloys. No metallurgical answer to the requirement for high-strength corrosion-resistant alloys was, therefore, apparent, and Evans suggested that the most likely solution lay in the direction of treatment of, or additives to, the oil.

Many analyses of oil ashes have been published and suffice to show that extremely wide variations occur. Shirey[4] has reported vanadium contents between a trace and 22 per cent and Kottcamp and Crockett[5] have shown values between 0·5 and 35 per cent. Evans[3] recorded ashes with vanadium contents between 3 and 44·5 per cent, sodium contents between 1 and 15·5 per cent, and iron contents between 3·5 and 46·5 per cent. Thus, no composition can be regarded as average or typical, and tests are of significance only with regard to the particular ash used.

Experience gained in running a gas turbine on a residual oil has been reported by Bucher.[6] The turbine contained blades made from a variety of materials, and was run for 300 hr on an oil with an ash content of 0·046 per cent and a vanadium content of 0·0139 per cent (equivalent to 30 per cent vanadium in the ash). Considerable fouling of the turbine occurred, resulting in a total power reduction to 40 per cent of the original output. Corrosive attack by ash was found only in the first two stages, *i.e.* where the temperature was above about 600° C, and all blades except those made from high-nickel alloys were affected. This observation appears to be in conflict with Evans' conclusions.

Various suggestions have been made to combat ash

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corrosion by treatment of the oil in such a way as to remove the corrosive constituents or to render them harmless and, while the ultimate solution of the problem will most likely be found by such methods, no entirely satisfactory treatment has yet been found.

It has been established by previous investigations that all alloys which have been tested are corroded to some extent by vanadium pentoxide at temperatures above about 600° C. Constructors of equipment in which residual oils are burnt are therefore faced with the problem of selecting, from those materials which are suitable in other respects, such as strength under operating conditions, cost, etc., the one showing the greatest resistance to corrosive attack. The work to be described was undertaken with the object of providing information which would help to solve this problem. The investigations carried out fall into two main classes:

(i) determination of the rate of corrosive attack under various conditions;

(ii) determination of the effect of corrosion on mechanical properties.

MATERIALS USED

The materials studied were mainly nickel–chromium heat-resisting alloys of various types, but a few samples of austenitic stainless steel and a single example of a cobalt-base alloy were also included. Compositions of the materials are recorded in Table I.

TABLE I

Nominal Compositions of Alloys

Alloy no.	Composition, %									
	C	Si	Cr	Ni	Co	Fe	Mo	Ti	Al	Others
1	0·1	0·6	18	8	—	Bal.	—	—	—	—
2	0·1	0·6	18	8	—	Bal.	3	—	—	—
3	0·1	0·6	25	20	—	Bal.	—	—	—	—
4	0·12	0·5	18	12	—	Bal.	—	—	—	1 Nb
5	0·4	1·0	13	13	10	Bal.	2	—	—	2½ W, 2 Nb
6	0·27	0·5	19	10	Bal.	15	2	—	—	3 V, 1 Nb
7	0·1	0·5	20	Bal.	—	—	—	0·5	—	—
8	0·05	0·5	20	Bal.	—	—	—	2·3	1·2	—
9	0·05	0·5	20	Bal.	20	—	—	2·3	1·2	—
10	0·1	0·5	18	37	—	Bal.	—	—	—	—
11	0·1	2·0	18	37	—	Bal.	—	—	—	—
12	0·05	0·5	20	Bal.	—	—	—	—	3·5	—
13	0·05	0·5	14	Bal.	—	6	—	—	—	—
14	—	10	—	Bal.	—	—	—	—	—	3 Cu
15	—	5	15	Bal.	—	—	—	—	—	—
16	—	10	14	Bal.	—	—	—	—	—	—
17	—	15	15	Bal.	—	—	—	—	—	—
18	0·03	0·02	—	Bal.	—	0·2	—	—	—	—

SCALING TESTS WITHOUT STRESS

Tests were first carried out to determine the effect of vanadium pentoxide, and of mixtures of this oxide with sodium or calcium sulphate, on the resistance of the various alloys to scaling when heated at 850° C. The samples of the alloys were in the form of sheet, strip, or cast plate, having an area of 1 sq. in. approx, and separate weighed samples of the various materials, on which 5 or 10 mg of vanadium pentoxide had been placed, were heated for 100 to 250 hr at 850° C in an electrically heated muffle furnace. The samples were then descaled by electrolytic treatment in molten caustic soda, followed by an acid dip, and the loss in weight was determined. Blank specimens without vanadium pentoxide were treated by the same heating and descaling cycle, in order to provide an approximate correction for the scaling due to oxidation in air.

In a further series of tests 10 mg of vanadium pentoxide were supplied to the specimens daily. These latter experiments included tests on cast nickel–chromium–silicon alloys, since the early results showed that nickel–chromium alloys were least attacked of the alloys examined, and high silicon contents had been reported as advantageous in iron-base alloys. A sample of cast plate of a nickel–silicon–copper alloy was also included. The results obtained are recorded in Tables II, III, and IV, the materials being arranged approximately in order of decreasing severity of attack.

TABLE II

Weight-loss of Specimens Heated at 850° C for 100 hr in Contact with Varying Amounts of Vanadium Pentoxide

Alloy no.	Type	Weight of V_2O_5, mg	Weight-loss, mg	Loss due to V_2O_5 mg
2	18 Cr–8 Ni–3 Mo steel	0	49·9	—
		5·6	696·0	646·1
		10·6	665·0	615·1
3	25 Cr–20 Ni steel	0	27·2	—
		4·6	349·6	322·4
		10·6	543·1	515·9
11	37 Ni–18 Cr–2 Si	0	39·2	—
		5·0	313·8	274·6
		10·0	425·8	386·6
1	18 Cr–8 Ni steel	0	20·5	—
		4·6	240·2	219·7
		10·4	345·4	324·9
18	Nickel	0	320·2	—
		5·4	391·6	71·4
		10·2	424·4	104·2
12	20 Cr–4 Al nickel	0	17·3	—
		5·2	69·2	51·9
		9·6	115·4	98·1
8	20 Cr–2½ Ti nickel	0	148·4	—
		6·2	221·6	73·2
		9·6	184·7	36·3
9	20 Cr–20 Co–2½ Ti nickel	0	47·8	—
		5·3	76·9	29·1
		9·3	97·9	50·1
7	80 Ni–20 Cr	0	20·4	—
		5·8	35·1	14·7
		10·4	37·6	17·2
13	80 Ni–14 Cr–6 Fe	0	15·2	—
		5·8	28·6	13·4
		10·6	35·0	19·8

The weight-loss measurements show that the nickel–chromium alloys are more resistant to corrosion than the austenitic steels, and that the molybdenum-

TABLE III

Weight-loss of Specimens Heated at 850° C for 250 hr in Contact with Varying Amounts of Vanadium Pentoxide

Alloy no.	Type	Weight of V_2O_5, mg	Weight-loss, mg	Loss due to V_2O_5, mg
2	18 Cr–8 Ni–3 Mo steel	0	79·0	—
		4·6	429·0	350·0
		10·0	624·1	545·1
3	25 Cr–20 Ni steel	0	53·6	—
		5·4	349·6	296·0
		10·8	531·7	478·1
1	18 Cr–8 Ni steel	0	24·2	—
		5·6	349·0	324·8
		10·0	394·6	370·4
11	37 Ni–18 Cr–2 Si	0	36·2	—
		5·6	341·6	305·4
		10·0	417·8	381·6
18	Nickel	0	793·6	—
		5·2	571·4	—
		10·8	457·2	—
12	20 Cr–4 Al nickel	0	16·0	—
		5·6	151·8	135·8
		10·4	163·0	147·0
7	80 Ni–20 Cr	0	21·8	—
		5·0	30·2	8·4
		9·2	51·9	30·1
8	20 Cr–2½ Ti nickel	0	307·9	—
		4·8	245·6	—
		9·6	257·4	—
9	20 Cr–20 Co–2½ Ti nickel	0	54·2	—
		4·2	127·6	73·4
		9·2	108·4	54·2
13	80 Ni–14 Cr–6 Fe	0	13·6	—
		5·8	22·6	9·0
		9·8	36·0	11·4

TABLE IV

Weight-loss of Specimens Heated at 850° C for 284 hr with Additions of 10 mg of Vanadium Pentoxide Every 24 hr

Alloy no.	Type	Weight-loss, mg	Weight-loss without V_2O_5, mg	Loss due to V_2O_5, mg
2	18 Cr–8 Ni–3 Mo steel	1674 †	54 *†	1620 †
3	25 Cr–20 Ni steel	1494	60 *	1434
1	18 Cr–8 Ni steel	1325	27 *	1298
11	37 Ni–18 Cr–2 Si	1054	40 *	1014
18	Nickel	582	880 *	Nil
12	20 Cr–4 Al nickel	280	18 *	262
7	80 Ni–20 Cr	194	24 *	170
8	20 Cr–2½ Ti nickel	290	88	202
9	20 Cr–20 Co–2½ Ti nickel	236	61 *	175
13	80 Ni–14 Cr–6 Fe	186	15 *	171
14	10 Si–3 Cu nickel	435	416	19
15	15 Cr–5 Si nickel	165·0	54·8	110·2
16	14 Cr–10 Si nickel	151·5	19·5	132·0
17	15 Cr–15 Si nickel	208·1	65·1	143·0

* Taken in proportion to time of treatment from Table III.
† Test discontinued after 168 hr.

containing 18 Cr–8 Ni austenitic steel No. 2 is attacked about twice as severely as the same composition without molybdenum No. 1. The severity of attack on the 37 Ni–18 Cr–2 Si alloy No. 11 was similar to that on the austenitic steels.

In general, the attack on nickel-base alloys was only about one-tenth of that on iron-base alloys, but this factor varied somewhat with the amount of vanadium oxide present, the difference being rather less marked in the tests in which 10 mg of vanadium pentoxide were applied daily than in tests where 5 or 10 mg were applied only at the beginning of the test. Similarly, the results for the nickel alloys themselves show less spread when the amount of vanadium pentoxide is greater. Thus, after the more severe test, the alloys Nos. 8, 9, and 12 were corroded to only about the same extent as nickel–chromium alloys without titanium or aluminium, whereas in the tests in which only single additions of vanadium pentoxide were made, these alloys showed up to 5 times as much corrosion as the nickel–chromium alloys.

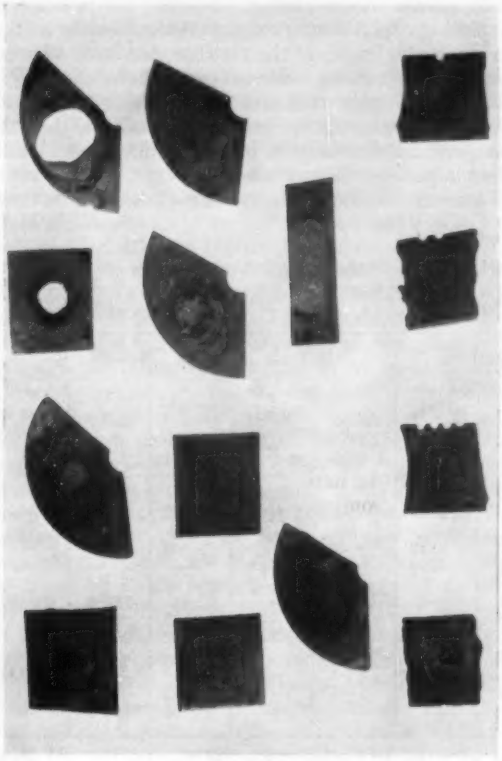
The nickel–chromium–silicon alloys Nos. 15–17 gave better corrosion-resistance than the other nickel–chromium type alloys and the 15 Cr–5 Si alloy No. 15 showed the smallest weight-loss of any alloy so far examined. The loss of weight was, however, reduced to only about two-thirds by addition of silicon.

In view of the nature of the tests and the fact that the nickel–chromium–silicon alloys were exposed in the cast condition while the other materials were tested in the form of rolled sheet or strip, this improvement seems too small to be regarded as really significant. The addition of more silicon, 10 or 15 per cent Nos. 16 and 17, did not cause progressive improvement in corrosion-resistance: the loss in weight of these alloys was greater than for the 5 per cent silicon alloy, though still rather less than for the silicon-free alloys.

The superiority of the nickel alloys is strikingly illustrated in Fig 1, which shows the appearance of the samples which had been treated daily with vanadium pentoxide. Complete penetration of the austenitic steels Nos. 1 and 2 had occurred. In the molybdenum-containing steel No. 2, penetration of the 0·02-inch thick sample occurred after only five days' testing, and the test was discontinued after seven days. The weight-loss measurements suggest that, had the samples been of the same thickness, penetration would have occurred in the 25 Cr–20 Ni stainless steel No. 3 and possibly also in the 37 Ni–18 Cr–2 Si alloy No. 11.

The nickel–silicon–copper No. 14 alloy and pure nickel No. 18 were much more readily oxidized in air than any of the other materials, as is shown by the weight-loss for the blank specimens. The magnitude of the blank correction in these cases renders the determination of the loss in weight due to vanadium pentoxide of little value, but it seems clear that the amount of attack by vanadium pentoxide is small and has not increased in proportion to the increase in normal atmospheric oxidation of these materials, as compared with chromium-containing alloys. It appears, from the tests so far carried out, that the action of vanadium

pentoxide may be limited to attack of the chromium-containing scales which are normally protective, and that where no such coating is formed the rate of attack is only of the same order as would be expected from oxidation in air. The results for pure nickel No. 18 (Tables III and IV) suggest that the vanadium oxide slag may even have a slight protective effect, since the loss in weight of the blank specimen was appreciably greater than that of the specimens treated with vanadium pentoxide.



Alloy Number

2	18	12	14
1	7		15
3	8	13	16
11	9		17

FIG 1

APPEARANCE OF TEST SPECIMENS OF DIFFERENT MATERIALS HEATED AT 850° C FOR 284 HR WITH ADDITIONS OF 10 MG VANADIUM PENTOXIDE EVERY 24 HR (× $\frac{1}{3}$)

Descaled electrolytically in caustic soda.

The results for the titanium-containing nickel–chromium alloy No. 8 (Tables II and III) also show a somewhat large "blank," which in Table III is greater than the loss in weight with vanadium oxide present. It is believed that this was due to the sheet having been rather heavily oxidized, leading to surface impoverishment in chromium, and then having the protective oxide film removed by pickling without sufficient removal of metal to get below the chromium-depleted layer. For the subsequent experiments, the results of which are given in Table IV, this difficulty was overcome by grinding the surface of the specimens before testing.

EFFECTS OF CORROSION ON HIGH-TEMPERATURE PROPERTIES

Stress–Rupture Tests

In order to assess the effects of ash corrosion on the stress–rupture properties of high-temperature alloys, a suitable test method had to be developed. In service relatively small amounts of fuel ash are present in the products of combustion: the amount of "active contaminants" deposited on the components is initially very low, and gradually builds up. Fuel-ash contamination is most serious in applications requiring fairly long lives, where the stresses are comparatively low. Accurate reproduction of such service conditions would have involved long-time stress–rupture testing in controlled atmospheres resembling the products of combustion of fuel oil, with continuous injection of small quantities of the contaminants. For the desired survey of materials and the generalized study of the combined effects of stress and fuel-ash contamination, a more rapid test was required, with, as far as possible, accurate control of the amount of reagent applied. The equipment and test technique selected to meet these requirements are described below:

The stress–rupture testing machine enabled a test bar of an alloy to be maintained at the required uniform temperature with an accuracy of about ±3° C, and to be subjected to a constant tensile load which was maintained until the bar fractured. The effect of corrosion on the stress–rupture properties of an alloy was assessed by the reduction in life at a given stress. It must be remembered that the life is very sensitive to change in stress, so that a very marked change in life may represent only a relatively small change in effective strength of the material.

The testing machine consisted of eight units within a single annular furnace maintained at a uniform temperature: these were arranged in a circle around the central pillar of the machine, and loading was by a lever system. The test bar and loading shackles of each unit passed through an Inconel tube fixed into the furnace. The test bar had a parallel portion $\frac{3}{4}$ in. long and 0·1305 inch dia, with $\frac{1}{4}$-inch Whitworth screwed ends.

A standard test was first developed, by experiments with test bars, of 18 Cr–8 Ni austenitic steel No. 1 coated in various ways with vanadium pentoxide, and bars of the titanium-containing nickel–chromium alloy No. 8 coated with a 50–50 mixture of vanadium pentoxide and sodium sulphate. This test was then applied to all the materials studied, using the contaminants (1) separately and (2) together in 75–25, 50–50, and 25–75 mixtures (the figures are quoted in the order V_2O_5/Na_2SO_4 throughout the paper). The stresses applied were intended to give a life in the range 100

to 300 hr for each material without contamination. In fact, the lives obtained on some alloys fell outside the range, but the results were sufficiently consistent to permit comparison of the behaviour of the more important alloys.

Three methods of applying the contaminant to the surface of the test bar were tried, with results which are detailed later:

(*a*) A suspension of the powder in a liquid carrier was painted on the surface of the bar. The bar was weighed without the deposit and after the coating had dried, so that the weight of contaminant was known. It was thought that water was not an ideal carrier, because sodium sulphate is soluble in water while vanadium pentoxide is not, and as a result the proportions in the mixture may be affected. Various organic liquids were tried, *e.g.* carbon tetrachloride, benzene, ether, and acetone, but the dry coatings tended to crumble and fall off the test bar before it was inserted in the machine. The technique finally adopted was to use very small amounts of the mixtures, add only enough water to form a very stiff paste, and apply, as far as possible, all of it to the surface of the test bar, so that the proportion of the contaminants in the mixture was maintained.

(*b*) A similar suspension was painted on the bar before test and at regular intervals of 24 hr throughout the test. This meant unloading the bar and raising it out of the furnace tube, painting it as rapidly as possible, and lowering it again into its correct position. In this way gradual build-up of contaminant was simulated, although service conditions of continuous deposition were not even approximately reproduced. The weight of contaminant on the bar was not known.

(*c*) Test bars were machined to a modified design, incorporating a small cup at the lower end of the gauge length. This cup could be filled with the mixed powders, and the weight of contaminant could be controlled much more accurately than with painted coatings. In effect, the gauge length of the test bar was partly immersed in the molten reactants, as in Evans' [3] experiments.

In routine stress–rupture tests the hot junction of a platinum/platinum–rhodium thermocouple is tied to the gauge length of the test bar, but such a procedure could not be adopted with bars carrying a deposit of highly corrosive substances. Experience with the stress–rupture machine has shown that the temperature distribution is fairly uniform, and that the temperature in any tube carrying a test bar could be assessed with a fair degree of confidence from those of the tubes on either side. Tests with bars carrying contaminants were, therefore, carried out in four tubes, while intermediate tubes were used for other stress–rupture tests on which temperature measurements were carried out in the normal manner. In this way temperature control in all the tests was maintained without appreciable loss in reliability.

TABLE V

Comparison of Results Obtained by the Various Stress–Rupture Test Methods

Alloy no.	Type	Stress, tons/sq. in.	Contaminant	Standard bars					Bars with cups		
				Method (*a*)			Method (*b*)		Method (*c*)		
				Weight of contaminant, g	Life, hr	Loss in weight, g	Life, hr	Loss in weight, g	Weight of contaminant, g	Life, hr	Loss in weight, g
1	18 Cr–8 Ni steel	3	V_2O_5	0	94·6	0·0344	40	0·6385	0·0351	61·1	—
				0·0003	70	0·0928	34·4	—	0·0452	50	—
				0·0076	65	—	—	—	—	—	—
				0·0198	35	0·2712	—	—	—	—	—
				0·0725	26·1	0·5459	—	—	—	—	—
8	20 Cr–2½ Ti nickel	16	50–50	0	244·2	—	160·8	—	0	220·9	0·0460
				0·0632	175·8	—	—	—	0·0157	203·8	—
				—	—	—	—	—	0·0569	219·8	—
		15	50–50	0	330	—	88·9	—	0	282·8	0·0138
				0·0041	244·6	0·0681	—	—	0·0172	223·2	—
				0·0637	245	—	—	—	0·0503	265·2	—

After test the broken bars were descaled cathodically in molten caustic soda: the weight of the descaled test piece indicated the weight loss due to oxidation during test. In some cases the broken bars were used for micro-examination, or could not be removed from the shackle without loss of metal. The results are, therefore, far from complete.

Data obtained by the three methods of test were compared, in order to select the most consistent: the results of this comparison are given in Table V. For the 18 Cr–8 Ni steel the life given by method (*a*) is clearly dependent on the amount of contaminant added. Repeated coatings, method (*b*), give a life intermediate between the lives resulting from light and heavy single coats, while the bars with integral

cups containing 0·035 to 0·045 g vanadium pentoxide had a slightly reduced life, about equivalent to that for a standard bar with only 0·01 g vanadium pentoxide applied as a single coat. The results on alloy No. 8 suggest that the bars with integral cups were not significantly affected by the contaminant at either stress level, whereas the single coating on a standard bar produced a fairly small but significant reduction in life at both stresses. Repeated coatings in this case gave still shorter lives.

On the basis of these results it was considered that the coating painted on to the surface of the standard bar (method (*a*)) gave a more consistent indication of the effect on stress–rupture life than the cupped bar (method (*c*)). Since the single initial coating gave values which could be correlated with the amount of contaminant, and did not involve interruption of the test, method (*a*) was preferred to method (*b*).

The results of the standardized test at 750° C on the range of alloys, with different corroding mixtures, are given in Table VI. The contaminants have shortened the life under stress of all the materials, although life-to-rupture was not in all cases directly related to the weight of contaminant or to the weight of vanadium pentoxide in the coating, nor did the same mixture of contaminants have the most pronounced effect on all alloys. Heavier coatings often gave shorter lives, but there were many cases where this did not apply, particularly in the more oxidation-resistant alloys. The most significant reductions were obtained with the lowest stresses and the longest lives, and this must be borne in mind in any assessment of the likely practical effects of fuel ash on high-temperature components. This phenomenon was particularly pronounced in the alloys 5 and 9, where the most serious corrosive attack caused equally short lives at two levels of stress.

Comparison between different materials is facilitated by plotting the lives-to-rupture of bars tested with painted coatings as percentages of the life of the uncontaminated material. The graphs are shown in Fig 2. While it is difficult to make a valid estimate of the variation in life which can fairly be attributed to random scatter, it will be convenient to regard any reduction in the life-to-rupture by more than 25 per cent as a significant effect of contamination by fuel-ash constituents.

The austenitic creep-resistant steel No. 4 gave curves showing a gradual reduction in life-to-rupture as the proportion of vanadium pentoxide in the coating increased; the slight fluctuations in the curves are probably due to random scatter. A similar tendency was observed in the complex carbide-hardened steel No. 5, with a steep fall in life as the vanadium pentoxide content of the coating increased from 50 to 75 per cent, particularly in the curve for 8 tons/sq. in.

The results for the cobalt-base alloy No. 6 show that at 16 tons/sq. in. all coatings reduced the life by about 30 to 50 per cent. At 17 tons/sq. in. a similar trend is shown, but the results are more irregular.

TABLE VI

Stress–Rupture Test Results at 750° C

Alloy no.	Type	Coating V_2O_5	Coating Na_2SO_4	Weight, g	Stress, tons/sq. in.	Life, hr	Weight-loss, g
1	18 Cr–8 Ni steel *	—	—	—	8	1·0	0·0107
		—	—	—	5	17·4	—
		—	—	—	4	45·0	0·0104
4	18 Cr–13 Ni steel	—	—	—	5	135·0	—
		100	0	0·0394	5	64·8	—
		75	25	0·0443	5	89·1	—
		50	50	0·0640	5	74·1	—
		25	75	0·0786	5	70·9	0·0981
		0	100	0·2794	5	110·0	—
		—	—	—	4	260·8	0·0216
		100	0	0·0402	4	131·3	0·0713
		75	25	0·0663	4	143·8	0·5341
		50	50	0·2509	4	159·8	—
		25	75	0·1289	4	145·0	0·1596
		0	100	0·0617	4	189·0	0·0329
		100	0	0·0837	3	223·8	—
5	Complex carbide-hardened austenitic steel	—	—	—	9	129·2	0·0311
		—	—	—	9	116·0	0·0114
		100	0	0·1034	9	97·3	0·6142
		75	25	0·0740	9	35·8	0·8690
		50	50	0·0934	9	160·0	—
		25	75	0·0857	9	117·8	—
		0	100	0·0706	9	99·6	0·0277
		—	—	—	8	413·9	0·0240
		100	0	0·0740	8	750·0	—
		100	0	0·0671	8	40·0	—
		75	25	0·0638	8	35·0	1·4525
		50	50	0·0608	8	280·0	1·5203
		25	75	0·0323	8	373·3	0·8375
		0	100	0·0816	8	393·9	0·0568
6	Carbide-hardened cobalt alloy	—	—	—	17	74·9	—
		100	0	0·0521	17	35·0	—
		75	25	0·0974	17	68·6	0·0064
		50	50	0·0338	17	46·0	—
		25	75	0·0577	17	61·2	0·0085
		0	100	0·0856	17	67·1	—
		—	—	—	16	160·0	0·0134
		100	0	0·0297	16	108·9	0·1070
		75	25	0·0274	16	69·1	—
		50	50	0·0074	16	69·8	—
		25	75	0·0564	16	111·9	—
		0	100	0·0488	16	69·3	—
10	37 Ni–18 Cr	—	—	—	3	71·9	0·0055
		100	0	0·0935	3	55·7	0·0821
		75	25	0·0066	3	44·2	—
		75	25	0·0400	3	40·0	0·3424
		75	25	0·1194	3	45·4	0·4610
		50	50	0·0167	3	47·8	—
		25	75	0·0123	3	47·1	—
		0	100	0·3973	3	52·5	0·0072
13	80 Ni–14 Cr–6 Fe	—	—	—	5	145·2	—
		100	0	0·0435	5	145·2	—
		75	25	0·0450	5	98·0	—
		50	50	0·0390	5	85·3	0·0339
		25	75	0·0591	5	109·2	0·0056
		0	100	0·2324	5	139·3	0·0105
7	80 Ni–20 Cr	—	—	—	3	128·9	0·0084
		100	0	0·0283	3	107·3	0·0346
		75	25	0·0472	3	96·1	0·0458
		50	50	0·0451	3	95·1	—
		25	75	0·0463	3	90·3	0·0400
		0	100	0·1183	3	106·0	0·0088
8	20 Cr–2½ Ti nickel	—	—	—	16	294·2	0·0287
		100	0	0·0201	16	235·8	0·0754
		75	25	0·0534	16	218·6	0·0745
		50	50	0·0344	16	229·1	0·0996
		25	75	0·1404	16	294·6	0·0504
		0	100	0·1202	16	354·2	0·0225
		—	—	—	15	500·0	0·0228
		100	0	0·0536	15	468·2	0·0768
		75	25	0·0213	15	260·7	—
		50	50	0·0556	15	402·8	0·0850
		25	75	0·0397	15	385·0	0·0949
		0	100	0·2239	15	364·0	0·0639
9	20 Cr–20 Co–2½ Ti nickel	—	—	—	17	192·6	0·0138
		100	0	0·1520	17	195·4	—
		75	25	0·0435	17	78·5	0·0482
		50	50	0·0764	17	97·6	0·0667
		25	75	0·0855	17	134·6	0·0609
		0	100	0·0897	17	102·8	0·0225
		—	—	—	16	367·1	—
		100	0	N.D.	16	226·8	—
		75	25	0·0349	16	73·7	—
		50	50	0·0665	16	344·7	—
		25	75	0·0201	16	276·3	—
		0	100	0·4798	16	280·0	—

* See Table V. N.D. = Not determined.

The nickel-base alloys normally employed for resistance to oxidation but not to creep, *i.e.* Nos. 7, 10, and 13, had to be tested at relatively low stresses: a series of tests at one stress was thought to be sufficient. The alloys gave curves indicating that the

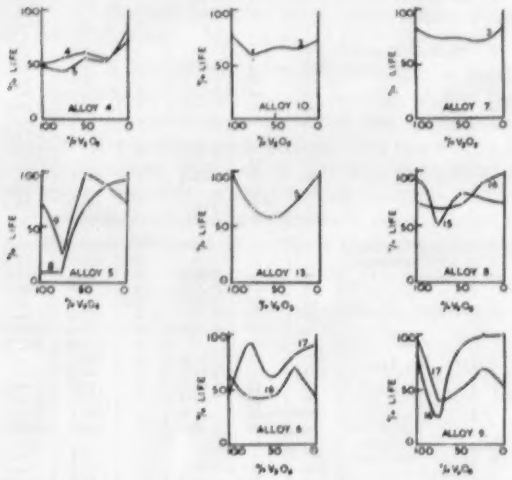


FIG 2

LIFE TO RUPTURE WITH COATINGS OF VANADIUM PENTOXIDE AND SODIUM SULPHATE IN VARYING PROPORTIONS

Life in percentage of life without corrosion.
Stress in tons per square inch indicated for each curve.

pure corroding substances were less effective than mixtures; this is especially pronounced in the case of the nickel–chromium–iron alloy No. 13, where neither pure vanadium pentoxide nor pure sodium sulphate affected the life-to-rupture, but the intermediate mixtures yielded a smooth curve with a minimum at 50–50. In the other two alloys the trend was similar, but less clearly marked.

For the creep-resistant nickel-base alloys Nos. 8 and 9, the 75–25 mixture was found to have greatest effect in reducing the life-to-rupture. Mixtures rich in sodium sulphate were observed to be erratic in effect; at one stress in each alloy there was little or no reduction in the life of bars bearing such coatings.

Fig 2 suggests that, of the alloys tested, the nickel–chromium alloy No. 7 has the best resistance to fuel-ash contamination and that the complex steel No. 5 is most susceptible to "ash" corrosion. The effect of the base composition of the different alloys is indicated in Table VII, where the minimum life, and the coating responsible for it, are recorded.

Table VII shows that the 75–25 mixture is generally the most potent in reducing the life-to-rupture; Fig 2 indicates that where an alloy gave a much shorter life with one coating than with any other, that coating was the 75–25 mixture. On the other hand, where the shortest life was obtained with another coating, the life with the 75–25 mixture was the next shortest and the difference was usually slight.

As far as the composition of the alloy is concerned, it appears from Table VII that, in alloys without cobalt, the higher the iron content, the greater is the effect of the vanadium-containing mixtures. The effect of cobalt is rather complex. In alloy No. 6, containing 46 per cent cobalt, the element seems to be analogous to iron, in that the alloy behaves like a cobalt-free alloy with an iron content equivalent to the actual level of iron + cobalt. The lower cobalt levels in alloys No. 5 and 9 are very much more detrimental than equivalent, or even much higher, iron contents; these alloys, containing, respectively, 10 and 20 per cent cobalt, show the greatest reduction in the life-to-rupture as a result of contamination.

TABLE VII

Summary of Influence of Corrosive Mixtures on Stress–Rupture Properties.

Alloy no.	Major constituents, percentage				Shortest life—expressed as percentage of life without corrosion	Coating	
	Ni	Cr	Co	Fe		V_2O_5	Na_2SO_4
1	8	18	—	73	27·6	100	0
4	12	18	—	67	43·8	75	25
5	13	13	10	55	8·5	100	0
						75	25
6	10	19	46	15	43·3	75	25
10	37	18	—	45	55·6	75	25
13	80	14	—	6	58·7	50	50
7	80	20	—	—	70·1	25	75
8	76	20	—	—	52·1	75	25
9	56	20	20	—	27·2	75	25

In many cases the weight of metal lost during the stress–rupture test was determined; the results are included in Tables V and VI. In the 18 Cr–8 Ni austenitic steel, where different weights of vanadium pentoxide were applied to the surface, the amount of metal lost by oxidation increased with the weight of the deposit, in spite of the fact that the life-to-rupture, and hence the time of oxidation, was appreciably reduced. It appears that the reduction in rupture life in this case was predominantly due to the reduction in cross-section of the test bar by relatively uniform and progressive scaling. Results available on bars of the nickel–chromium alloys carrying increasing deposits of the 50–50 mixture are insufficient to permit assessment of the effect of the weight of contaminant on the weight-loss due to oxidation.

Standard tests on all materials with various mixtures of vanadium pentoxide and sodium sulphate, see Table VI, show no consistent correlation between weight-loss, on the one hand, and either the weight of contaminant or the weight of vanadium pentoxide in the painted coating, on the other. However, there is generally a relation between the loss in weight and the life-to-rupture, although it is by no means clearly defined or absolutely consistent. The most important feature in these figures is that although the weight-loss of the uncontaminated samples is within the range 0 to 0·03 g, for all materials, the weight-loss of the contaminated samples varies very considerably.

For the austenitic steels weight-loss rises to a maximum value within the range 0·5 to 1·5 g, but for the nickel–chromium base alloys the weight-loss never exceeds 0·1 g. The nickel–chromium–iron alloy No. 10 and the cobalt-base alloy No. 6 are intermediate cases with the maximum weight-loss in the range 0·1 to 0·5 g.

TABLE VIII

Stress–Rupture Test Results at 870° C

Alloy no.	Type	Weight of coating, g	Stress, tons/sq. in.	Life, hr
5	Complex carbide-hardened austenitic steel	—	4	339·2
		0·0222	4	16·8
		—	3	1029·8
		0·0381	3	14·0
		0·1444	3	11·0
6	Carbide-hardened cobalt alloy	—	6	8·2
		—	6	11·0
		—	6	6·7
		0·0170	6	7·3
		0·1208	6	2·9
		—	3	146·6
		—	3	360·0
		—	3	185·8
		—	3	161·4
		—	3	166·2
		0·0323	3	57·4
		0·0633	3	86·4
8	20 Cr–2½ Ti nickel	—	5	300·0
		0·0715	5	294·1
		0·2651	5	271·1
		—	4	700·0
		0·0484	4	567·7
9	20 Cr–20 Co–2½ Ti nickel	—	5	268·4
		—	5	240·9
		0·0524	5	236·6
		0·1835	5	126·0
		0·3535	5	183·6

Additional stress–rupture tests in the presence of the 75 per cent V_2O_5 + 25 per cent Na_2SO_4 mixture were made on a few of the alloys at 870° C, since it was expected that the effects of corrosion would be aggravated at the higher temperature. The results of tests, with and without painted coatings, are recorded in Table VIII. The coated bars of the complex steel No. 5 suffered accelerated oxidation; a thick, spongy oxide layer was found after test, and the thin core of unoxidized metal probably failed rapidly in tension. Failure occurred in less than 17 hr, irrespective of the stress or the weight of the coating (above 0·0222 g) applied. At 750° C a similar observation was made with 75–25 coatings, but the life of coated bars was about 35 hr. It can, therefore, be concluded that the rise in temperature resulted in more severe accelerated oxidation, as was to be expected.

The reduction in life of the cobalt-base alloy No. 6, due to the coating, was very severe, roughly similar to that in comparable tests at 750° C. The titanium-hardened nickel–chromium alloy No. 8 showed only a very slight reduction, hardly exceeding the variation in lives due to random scatter, and it can be attributed to the effect of vanadium pentoxide only because the lives of coated bars were consistently shorter than those of clean bars in all tests at 870° C, and in all comparable tests at 750° C. With comparatively light coatings on the similar but cobalt-containing alloy No. 9, the reductions in life were very slight, whereas with heavier coatings the lives were considerably shortened.

MICROSCOPIC STUDIES

Microscopic examination of the broken stress–rupture bars was made, but after the tests at 750° C no significant differences could be detected between bars tested with a corrosive coating and those tested in clean air. The specimens in all cases showed an outer layer of scale, and fracture occurred by propagation of intercrystalline cracks, which were oxidized to some degree. In order to study the nature of the corrosive attack of vanadium pentoxide on the alloys dealt with in the present work, small specimens were prepared containing a shallow drilled hole which was packed with the oxide or an oxide–sulphate mixture, and these were heated at 1000° C for one week. It was hoped that the higher temperature would accelerate the attack sufficiently to make it more

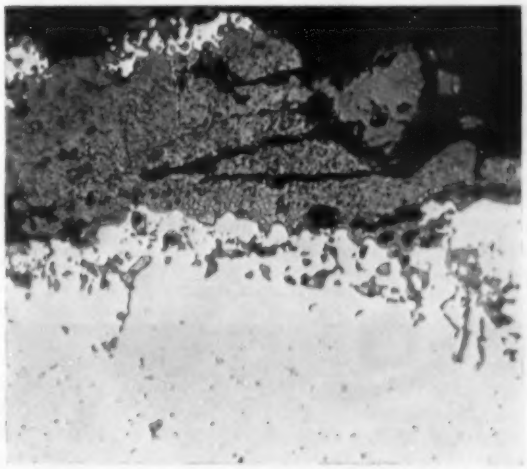


FIG 3

ALLOY NO. 8 HEATED AT 1000° C FOR 500 HR IN AIR (× 300)

readily understandable and stimulate a more general surface attack instead of one limited to susceptible points, but it must be borne in mind that the nature of the attack may thereby have been changed.

Figs 3, 4, and 5 illustrate the results obtained on the titanium-hardened nickel–chromium alloy No. 8.

Fig 3 shows the effect of heating an uncontaminated sample in air at 1000° C for 500 hr. An outer coherent scale layer was formed, with a band of intermingled oxide and metal lying between this and the unattacked metal. No clearly marked intergranular attack was apparent. Fig 4 shows the structure of the attacked metal within the drilled hole after heating at 1000° C

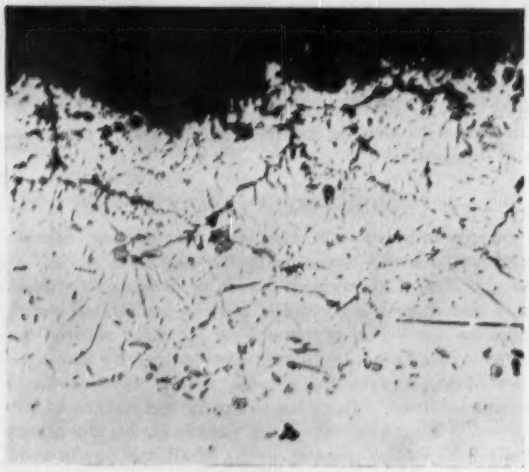


FIG 4

ALLOY NO. 8 HEATED AT 1000° C FOR ONE WEEK IN CONTACT WITH VANADIUM PENTOXIDE (× 300)

for one week with vanadium pentoxide in the hole. In this case the outer layer of scale is followed by a zone of intergranular attack in which an acicular phase also makes its appearance. The surface of the sample outside the drilled hole, where attack took place by vaporized vanadium pentoxide rather than by the liquid oxide, is shown in Fig 5. In this case, although intergranular attack is apparent, little of the acicular phase is visible. Alloy No. 9 was attacked in a similar manner, as is shown by Fig 6.

Alloy No. 10, the nickel–chromium–iron alloy containing about 45 per cent iron, suffered accelerated oxidation when heated in contact with vanadium pentoxide at 1000° C for one week. The region of the specimen in which rapid attack took place was adjacent to the hole containing the vanadium pentoxide, and was sharply differentiated from the normally attacked region, as shown in Fig 7. Presumably, such attack occurs only when an adequate supply of vanadium pentoxide is available, and it appears to

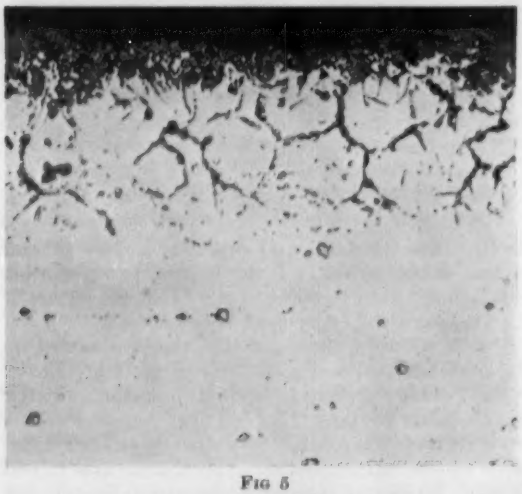


FIG 5

ALLOY NO. 8 HEATED TO 1000° C FOR ONE WEEK

Surface near to vanadium pentoxide. Showing effect of vaporized pentoxide.

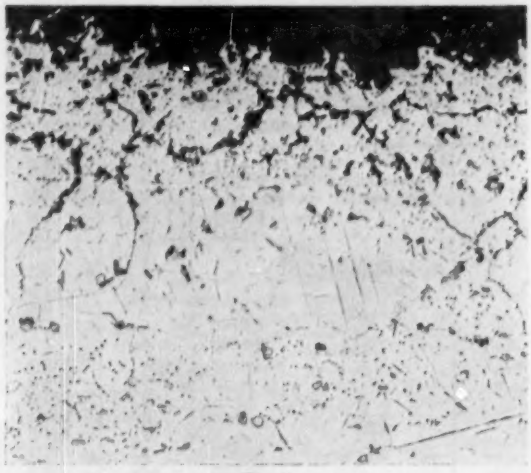


FIG 6

ALLOY NO. 9 HEATED TO 1000° C FOR ONE WEEK IN CONTACT WITH VANADIUM PENTOXIDE (× 300)

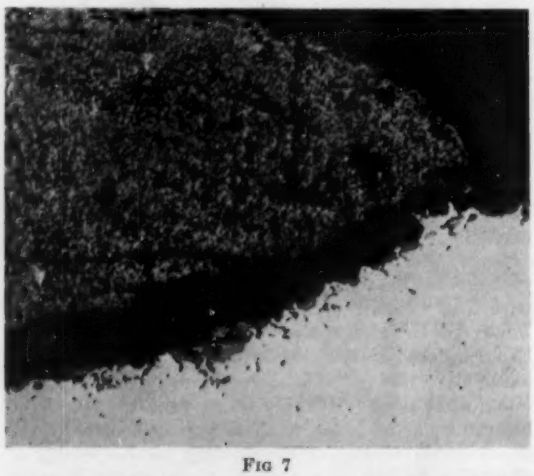


FIG 7

ALLOY NO. 10 HEATED AT 1000° C FOR ONE WEEK (× 100)

Edge of area of accelerated oxidation.

be similar in character to the "catastrophic oxidation" described by Leslie and Fontana [7] in connexion with certain molybdenum-containing alloys. The other alloys examined behaved in a similar manner to that observed with one or other of the two classes already described, the nickel–chromium-base alloys forming an outer scale with an inner layer of intergranular penetration, and the high-iron alloys suffering accelerated oxidation to a degree similar to that shown by

alloy No. 10, the scale–metal surface generally being fairly smooth, with little indication of intergranular attack. The cobalt-base alloy No. 6 formed a heavier scale layer than the nickel–chromium base alloys Nos. 8 and 9, with an underlying zone of intergranular penetration.

Similar tests carried out with vanadium pentoxide + 25 per cent sodium sulphate as the corroding medium, gave structures showing no significant differences from those produced by the pure vanadium pentoxide.

Interesting results were observed in examination of a sample of the nickel–chromium alloy No. 7, which had

FIG 8

SPECIMEN OF ALLOY NO. 7 AFTER EXPOSURE TO PRODUCTS OF COMBUSTION OF BUNKER C FUEL OIL (× ½)

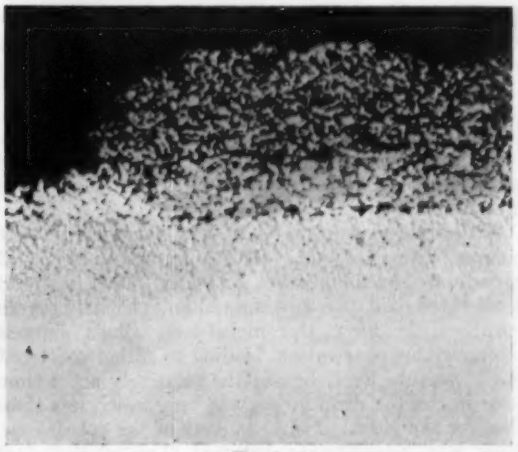


FIG 9

SECTION THROUGH EXCRESCENCE ON BAR SHOWN IN FIG 8 (× 100)

been subjected to corrosion by the products of combustion of a residual fuel oil (Bunker C), the test being of 700 hr duration at 750° C.* Unfortunately, the analyses of the oil and ash are not available, but the ash was known to contain a considerable proportion of vanadium pentoxide. The appearance of the test rod after electrolytic descaling is shown in Fig 8. Micro-sections were prepared through some of the wart-like excrescences, and these were found to consist of an intimate mixture of metal and scale, as illustrated in Fig 9. Underlying the wart was a layer characterized by the presence of a pale-grey phase. It was suspected that this phase was a sulphide, and it was indeed identified as chromium sulphide, Cr_2S_3, by the following procedure : A sample of the alloy was severely attacked by heating to about 900° C in the presence of sulphur vapour ; this formed a thick layer of a product with the same appearance and etching characteristics as the grey phase, which, unlike the normal oxide on this alloy, is darkened by electrolytic etching in 20 per cent caustic soda. This phase was separated from the metal by anodic solution in 5 per cent hydrochloric acid, and comparison of its X-ray powder pattern with the ASTM index of X-ray diffraction data proved it to be Cr_2S_3.

From the sample corroded in the oil-combustion test, material forming a wart was filed, and was found to be strongly magnetic, indicating severe loss of chromium from the original alloy, and X-ray powder photographs showed that the lattice parameter was approximately that of pure nickel. In addition to the diffraction pattern for the metallic matrix, the pattern for chromic oxide was identified, together with a few other very faint lines which could not be identified. It was thus concluded that the excrescences consisted primarily of nickel and chromic oxide, and from the structure visible under the microscope it appears that sulphur attack causes the formation of chromium sulphide, which is then oxidized to chromic oxide, thus rendering the sulphur available for further penetration into the alloy. Conversion of chromium metal to sulphide or oxide leaves the alloy impoverished in chromium, and eventually reduces the matrix to approximately pure nickel.

Spectrographic analysis of the material of the wart indicated the presence of only 0·1 to 0·2 per cent vanadium, so that although the ash undoubtedly stimulated the attack of the metal (since such marked attack at this temperature would be quite unexpected in the absence of the ash, even with high sulphur contents in the atmosphere) the vanadium does not enter to any appreciable extent into the structure of the corrosion growths. It seems probable that the vanadium pentoxide fluxes the normally protective oxide scale from the alloy, and that any sulphur compounds, either in the atmosphere or in the ash, are then able to attack the alloy without hindrance. This example of the type of corrosion which can occur in practice shows that any attempt to simplify the problem by using pure substances as the corroding media is liable to give very misleading results. The present work shows that the combined action of mixed reagents can be much more serious than that of either constituent alone, and indeed corrosion tests made with real or synthetic ashes, when heating is carried out in air, might yield very different results from those obtained in service if, for example, a sulphur-containing atmosphere were present.

CONSIDERATION OF RESULTS

The results obtained can be examined from two points of view : (1) to determine, so far as possible,

* The authors are indebted to Messrs John Brown and Company Ltd. for the test carried out in their laboratory, and for the opportunity of examining the sample.

the mechanisms whereby the presence of an ash accelerates the corrosion rate of an alloy, and (2) to assess the effect of such corrosion on the serviceability of a component.

The mechanism of vanadium pentoxide attack can, to some extent, be deduced from the results of the corrosion tests. It seems probable that the normally protective oxide layers are removed by solution in the vanadium pentoxide, with the result that the oxidation-resistance is reduced to a level substantially representative of that of the base metal in its initial state before the protective oxide film forms. It is not yet evident whether the vanadium pentoxide itself or oxygen in the atmosphere is the agent reacting with the alloy. The oxidation-resistance of both nickel-base and iron-base heat-resisting alloys is usually attributed to the formation of protective scales rich in chromium oxide. It would seem, therefore, that the solution of this oxide by the liquid vanadium pentoxide is the primary factor leading to the accelerated corrosion.

As oxidation proceeds and the chromium is preferentially removed from the alloy it is, of course, inevitable that the proportion of chromium to base metal in the remaining alloy is reduced and the nature of the base-metal oxide becomes of greater importance. The tests on pure nickel show that the oxidation rate is not increased by the presence of vanadium pentoxide, and this would seem to indicate that nickel oxide is not fluxed by vanadium pentoxide at 850° C, and is, therefore, a valuable constituent in the scale of alloys which have to resist the attack of this substance. The scaling test results do, in fact, demonstrate quite clearly that the nickel-base alloys are greatly superior to iron-base alloys, so far as resistance to the accelerating action of pure vanadium pentoxide on the rate of oxidation is concerned. However, it is apparent from the examination of the sample of alloy No. 7 corroded in the oil-combustion test chamber that the corrosive effects to be expected in practice are more complicated than those produced by vanadium pentoxide alone, and that the presence of sulphur is particularly important in this respect. The stress–rupture tests with mixtures of vanadium pentoxide and sodium sulphate did not provide evidence of severe attack leading to the formation of the wart-like growths similar to those shown in Fig 8, so that it appears possible that sulphur attack is more likely to occur from gaseous sulphur compounds present in the atmosphere, than from alkali sulphates present in the ash, although it has been shown that mixtures of vanadium pentoxide and sodium sulphate are more dangerous than vanadium pentoxide alone.

The apparent anomaly between the present results and those of Evans [3] in regard to the relative resistance to corrosive attack of low-nickel alloys and high-nickel or cobalt-base alloys is probably associated with sulphur attack rather than with the effects of vanadium, for Evans detected intergranular attack on Inconel (alloy No. 13) by his natural ash, which he suggested was due to sulphur. Investigations on the effect of different combinations of atmosphere and ash compositions on the corrosion behaviour of different alloys are obviously necessary.

The results of the standard stress–rupture test adopted for this work indicate that nickel–chromium-base alloys are more resistant to the effects of corrosion by mixtures of vanadium pentoxide and sodium sulphate than are iron-base alloys or the single cobalt-base alloy examined. Sodium sulphate alone has no very serious effect on the life of any of the high-temperature alloys, but additions of this substance to vanadium pentoxide in most cases intensify the effect of the latter. Although in such cases no evidence of sulphur attack of the alloys was obtained, it seems possible that small traces of sulphur from the sulphate could be responsible for this effect. It is suggested, on the basis of the results obtained, that the effect of vanadium pentoxide contamination on iron-rich alloys is to produce an effect similar to what has been called "catastrophic oxidation," *i.e.* the rapid bulk oxidation of the alloy, producing voluminous spongy oxide and a sharply defined, relatively smooth scale–metal interface. In nickel-rich alloys, on the other hand, oxide penetrates into the metal, preferentially along the grain boundaries, and thus reduces the stress-carrying capacity of the alloy, without abnormally severe oxidation as judged by weight changes. It is suggested that intergranular penetration is not observed in iron-rich alloys because the rate of advance of the bulk oxide is faster than the rate of intergranular attack.

The stress–rupture tests at 870° C confirmed the results of the tests at 750° C. In the presence of vanadium pentoxide the austenitic steel suffered accelerated oxidation and showed an extremely severe reduction in life: the nickel-base alloys showed intergranular penetration, leading to rather scattered stress–rupture lives, but in the relatively short-time tests made, the drop in life was very much less than that for the steel. The behaviour of the cobalt-base alloy was intermediate between that of the steel and that of the nickel-base alloys.

ACKNOWLEDGMENT

The authors' thanks are due to The Mond Nickel Co. Ltd. for permission to publish these results.

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CORRESPONDENCE

CARBON RESIDUE—CONRADSON OR RAMSBOTTOM?

The Editor, *Journal of the Institute of Petroleum.*

SIR,

I refer to the above article appearing in the June 1954 Journal of the Institute, and to the invitation to comment extended therein to interested users of the methods. The following comments are based on experience of the use of both methods for control analyses over a number of years:

(1) I agree with the suggestion that, if the interests of specification writers can be met, the Conradson method be deleted completely. Experience here has indicated that good repeatability is much more readily obtained by the Ramsbottom method, that actual operating time is less, that the technique is easier to apply, and that operation is less critical of the personal factor.

(2) Any interim dependence upon conversion tables should be as temporary as possible, and the acceptability of existing tables critically examined. We have been unable to substantiate the conversions published by ASTM, and the divergences involved have been of an order sufficient to cause rejection of the tables and the actual use of the Conradson method when specifications require.

(3) Details of the Ramsbottom apparatus and technique should be the subject of close co-operation between IP and ASTM. Of particular practical importance are the design of the coking bulb, the permissibility or otherwise of re-using, and, if re-usable, the recommended cleaning technique. If not already firm, investigation is also desirable into the admissibility or otherwise of steel bulbs.

Agreement should also be reached with ASTM on the basic design of the bath and ancillary equipment.

Yours faithfully,

THE DOMINION LABORATORY,
F. J. T. GRIGG, Director.

Wellington, C.I.,
27 *September* 1954.

The Editor, *Journal of the Institute of Petroleum.*

SIR,

Although it is almost six months (*J. Inst. Petrol.*, 1954, **40**, 175) since the Institute of Petroleum sought the views of interested parties, it should not be assumed that the apparent lack of response to this request signifies lack of interest. This Company is very much concerned with specifications that include carbon residue by the Conradson test, and it has taken some little time before we have been able to state our considered views.

At the outset, we are in complete agreement with the facts as stated in the articles referred to above. It remains to consider the three possibilities, items (*a*), (*b*), and (*c*), set forth by Sub-committee No. 4 of the Institute of Petroleum. In our view, the first thing to be done is to proceed on the basis that a reliable conversion table between Ramsbottom and Conradson values can be established (item (*b*)). Any other action (items (*a*) and (*c*)) should therefore await the outcome of item (*b*).

It is noted that the Institute is endeavouring to produce the conversion table; in view of the wide application of the two carbon-residue methods we believe that co-operation between the Standardization Committee of the Institute of Petroleum and ASTM Committee D-2 is not only essential but should be established before substantial experimental work is put in hand on this side. One point which must be settled is the technical equivalence of the ASTM and IP Ramsbottom methods.

We believe that it will not be disputed that the Conradson–Ramsbottom conversions published by the ASTM do not apply to such petroleum products as are marketed in the U.K.; at least, the discrepancies which we have found are sufficient to cause us to reject the use of the tables for specification purposes.

There is next the difficult question of the conversions of carbon-residue values at the low end of the scale. We should like to suggest to the IP technical group concerned that it would be worthwhile devoting considerable attention to Conradson carbon residues in the region of 0·01–0·10 per cent, and the corresponding Ramsbottom range, in order that the current device of resorting to the 10 per cent residuum procedure can be withdrawn. We believe that it is highly desirable for any authoritative Conradson–Ramsbottom table, or curve, to be continuous. At this stage, however, because of the experimental difficulties which are sometimes encountered in the determination of Ramsbottom values of gas oils, we would not recommend the withdrawal of the 10 per cent residuum procedures. This is a matter which is best considered when the co-operative testing programme has been completed.

We have noted that the IP Lubricants Subcommittee has withdrawn its recognition of the Conradson test. We believe, however that although the future IP conversion table should exclude lubricating oils it would be unwise to exclude lubricating oils in the proposed co-operative programme of test. It is important to know if both fuel oils and lubricating oils do, or do not, lie on the same conversion curve.

Yours faithfully,

FOR THE SHELL PETROLEUM COMPANY LTD.
H. HYAMS

London,
29 *November* 1954.

CORRECTIONS TO IP STANDARD METHODS

CERTAIN corrections to the methods appearing in "Standard Methods for Testing Petroleum and Its Products," 14th Edition, 1955, have been noted. They are :

Tetraethyl Lead in Gasoline (*IP* 116/55)

Section 8(*a*). The letter C at the top of the oil seal should be deleted.

In line 3 on page 549, the letter D should be deleted.

Section 10(*a*). In line 7, for "50 ml" read "15 ml."

ERRATA

EMULSIFICATION TEST FOR MARINE ENGINE OILS

Page 371. Volume 40, December 1954.

Section 3(*a*). *Graduated Cylinder.* Add "The bottom should be flat and at right angles to the walls."

Section 3(*c*). *Drive Unit.* After "1500 r.p.m." add "under conditions of the test."

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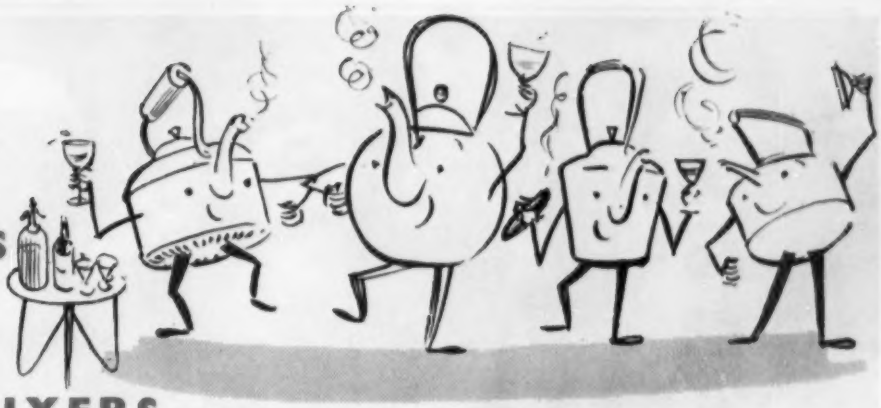

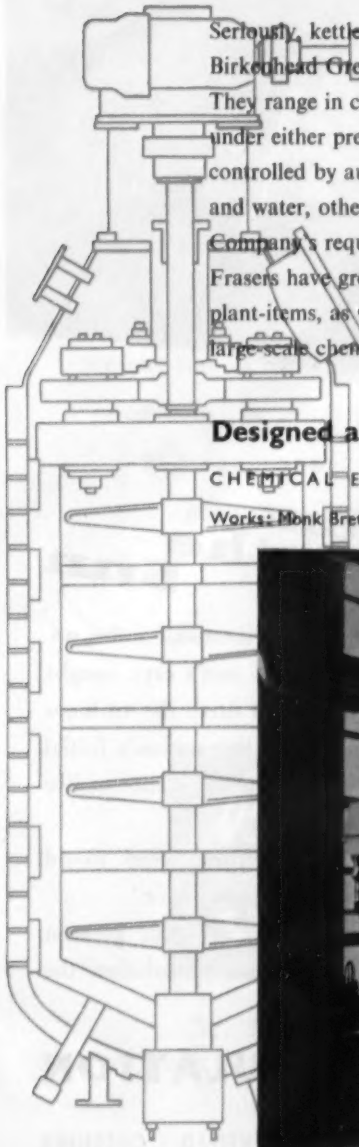

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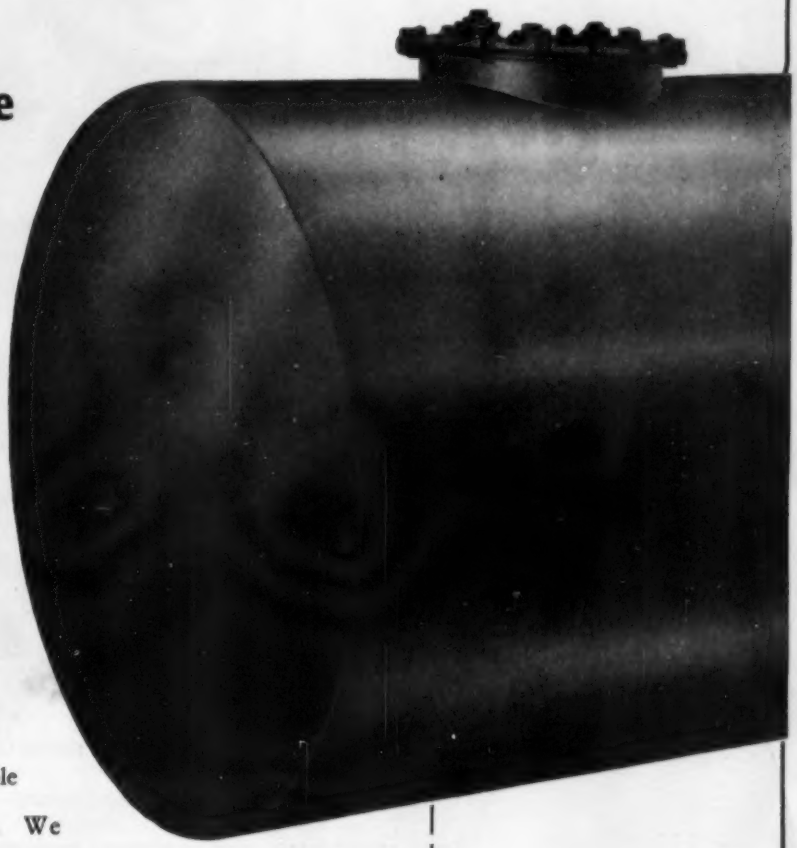

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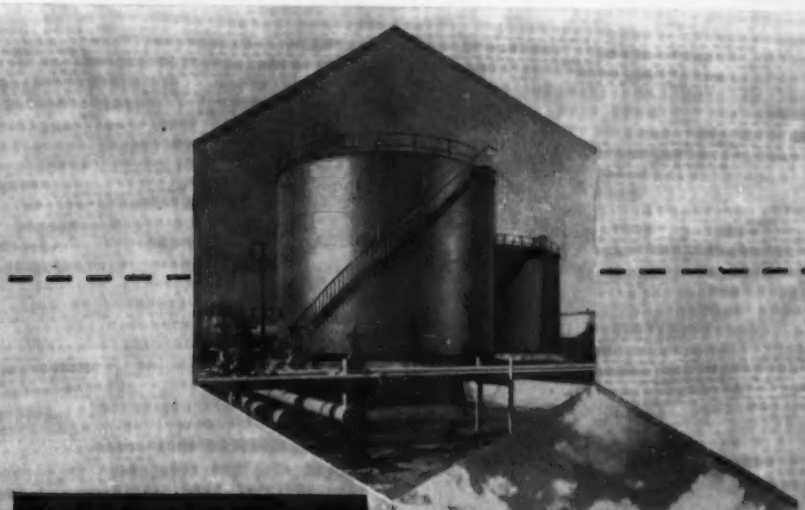

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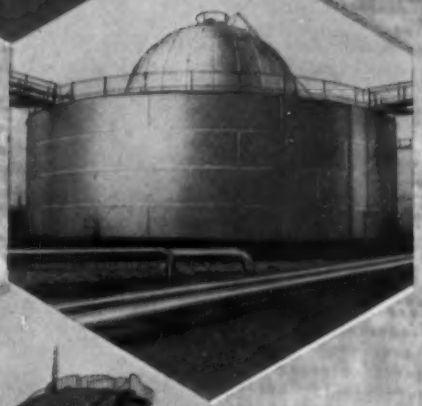

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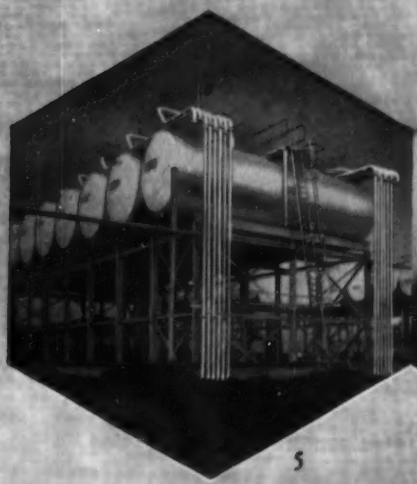

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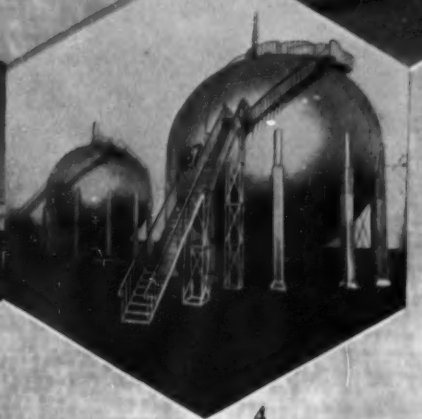

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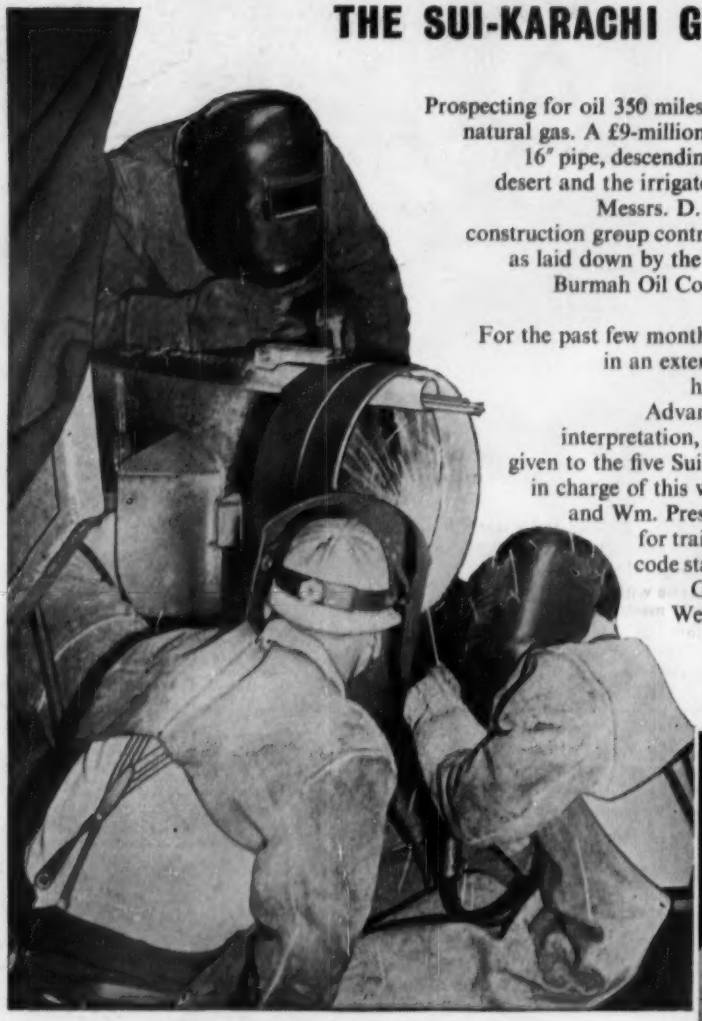

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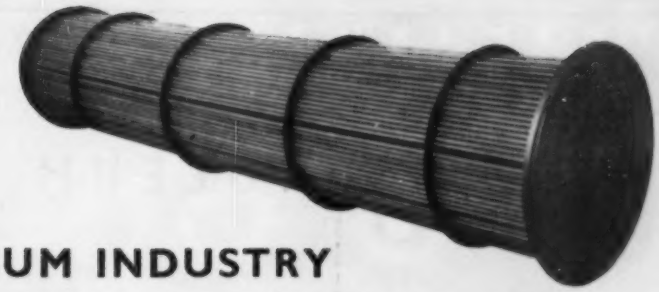

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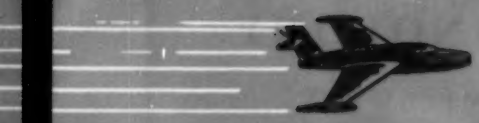

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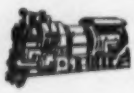

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